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VOL. X., No. 3 JUNE, 1927

SENSORY, SECRETORY AND ELECTRICAL CHANGES IN THE SKIN FOLLOWING BODILY EXCITATION

BY CHESTER W. DARROW[1]

The University of Chicago

The galvanic skin reflex[2] has frequently been attributed to changes in the rate of secretion of the sweat glands, and yet no mention has been made of any simultaneous records of variations in the two phenomena. Leva[3] demonstrated that the electrical changes are most pronounced in those parts of the body where the sweat glands are most numerous. By the use of a capsule filled with calcium chloride and exposed for relatively long periods (10 minutes) over various surfaces of the body, Waller[4] was able to demonstrate, by

[1] I wish to express my indebtedness to Drs. H. A. Carr, E. S. Robinson, L. L. Thurstone, F. A. Kingsbury, and F. A. C. Perrin of the Department of Psychology, Drs. A. J. Carlson, Margaret Miller and N. Kleitman of the Department of Physiology, and Dr. C. J. Herrick of the Department of Anatomy, The University of Chicago, and to Drs. G. J. Rich and K. S. Lashley for suggestions during the conduct of the experiment and assistance in the preparation of this manuscript. To the many martyrs to science who have served as subjects and been victims of my persecutions I owe an obligation which I hope I may never have an opportunity to repay in kind. Special thanks are due to Dr. F. C. Koch of the Department of Physiological Chemistry for the loan of the electrocardiograph and to the Department of Psychology for supplying the other equipment that made this research possible.

[2] In this article we shall follow the lead of Gildemeister (Martin Gildemeister, *Arch. f. d. ges. Physiol.*, 1922, **197**, 432–436), employing the term *galvanic skin reflex* (galvanische Hautreflex) because it is less misleading than the term psychogalvanic reflex.

[3] J. Leva, *Münch. med. Woch.*, 1913, **43**, 2386.

[4] A. D. Waller, *Proc. Roy. Soc.*, 1919, **91**, 17–31.

changes in the weight of the salt, differences in the amount of the insensible perspiration which were correlated with variations in the magnitude of the galvanic reflex in the different parts. He obtained neither continuous records of moisture change, however, nor simultaneous data on the two phenomena. No standard apparatus seems to be available for this purpose.

The following article presents (1) a description of an apparatus securing continuous records of moisture changes in the skin, (2) a study of the galvanic skin reflex and its relation to the secretory processes, and (3) a study of certain cutaneous sensations accompanying these changes.

Apparatus and Procedure

The moisture-sensitive part of the apparatus is represented in reduced size by Figs. 1, 2, and 3, Plate I. It consists of (1) a zinc electrode with an opening in the center, (2) a spirometer supplying dry air to the skin surface to which the electrode is applied, (3) a band of fine silk fibers coated with a deliquescent salt and stretched above the central opening, and (4) electrical connections with the zinc plate and with the ends of the fibers.

The electrode consists of the zinc plate, *Zn* (Plate I), 1½-in. in diameter by $\frac{1}{16}$-in. thick, having an opening, *C*, in the center. It is backed by ⅛-in. of bakelite, *Ba*, having the opening, *h*, in the center.

The air from the relatively simple spirometer, *Sp*, passes through a calcium chloride tube, *CaCl*; a stop cock, *St*; and tubes, *tt* and *gg*, leading to the central opening in the zinc plate.

The silk fibers, *f*, single strands of untwisted silk, are stretched in a band across the opening, *h*, from the air chamber, their ends being fastened by the brass plates, *dd*. A layer of tinfoil is placed between the fibers and the bakelite and connected with the brass plates to improve the electrical conduction. The central portion of the device is protected above by the plate of bakelite, *J*. The fibers are prepared by soaking them in a saturated solution of calcium chloride [5] after which they are pressed relatively dry. In this condition the vapor tension of the salt-fiber combination is such as to be most easily affected by the minute changes in the moisture of the air current from the body surface. For some reason not yet determined the freshly prepared fibers are the most sensitive.

[5] A mixture of glycerine as hygroscopic agent, with sodium sulphate as the ionizable substance to render the fibers conductive when moist, seems to have the advantage of being more stable than $CaCl_2$. We are indebted for the suggestion, through the agency of Dr. H. M. Johnson of Mellon Institute, to Dr. P. W. Cobb of Nela Park, Cleveland, and Dr. L. C. Grondahl of the Union Switch Company.

Electrical connections are made by means of the binding post, *i*, with the zinc plate; and by means of the posts, *ee*, with the brass strips holding the ends of the fibers.

The current of air from the spirometer passes through the calcium chloride tube to be dried; then comes into contact with the body surface in the center of the zinc electrode and, if that surface is moist, is increased in humidity. Immediately thereafter the dampened air touches the fibers stretched above this region, imparts to them some of its moisture, and thereby reduces their electrical resistance. On the contrary, if the body surface is dry the undampened current of air on reaching the fibers relieves them of any surplus moisture they may contain and raises their resistance. Thus the electrical conductivity of the fibers varies directly with the moisture secretion of the part of the body tested. Changes in this conductivity are registered by a galvanometer, *G*. Then, by using the zinc base of the apparatus, *Zn*, as one of a pair of electrodes, *EE'*, connected with a second galvanometer, *G'*, it is possible to secure the galvanic skin reflex from approximately the same region as gives the moisture record.

The minute amount of moisture to which the device is sensitive is shown by the following test. If the apparatus is moved face down along a perfectly dry flat surface, no deflection will be noted. If, then, the finger, damp only with the normal amount of insensible perspiration, is rubbed over the surface, the apparatus when moved over the slightly moistened place will show a deflection.

The latent time of the moisture-recording apparatus should be subtracted from each result representing the time of the moisture deflections. This latent time is measured by moving the moisture recorder over a ¼-in. opening in an aluminum plate behind which is placed wet filter paper. Movement over the opening and away from it respectively pulls and releases the string of the signal marker. With this arrangement it is possible to obtain a record on the photographic film (1) of the time between the beginning of the signal-mark and the initial rise of the moisture curve, and (2) of the time between the termination of the signal mark and the peak of the moisture curve.

(1) Time from exposure of apparatus to moisture until beginning of deflection ..... 0.2 seconds
(2) Time from removal of moisture until peak of deflection ..... 0.5 seconds

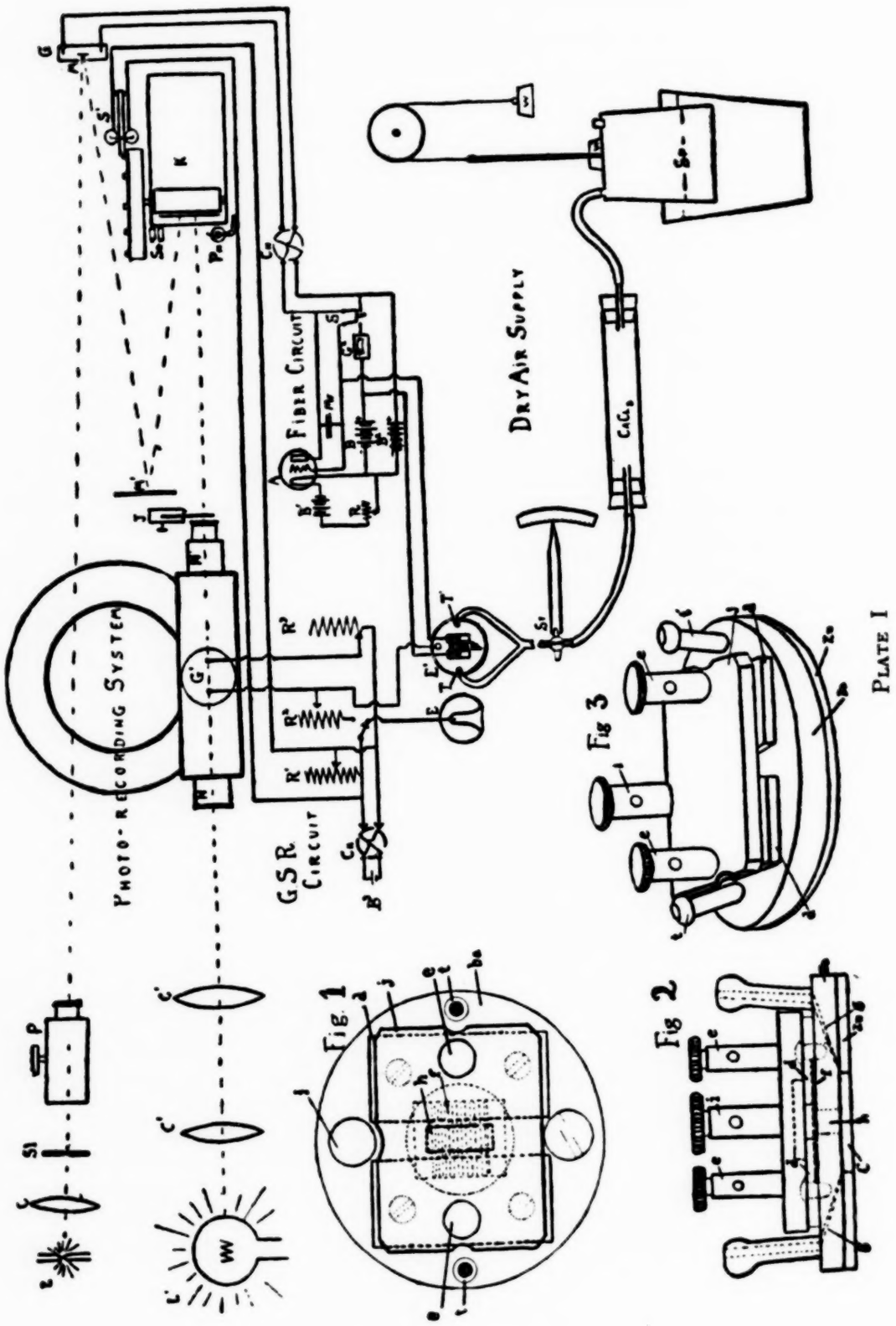
PHOTO-RECORDING SYSTEM
GSR CIRCUIT
FIBER CIRCUIT
DRY AIR SUPPLY
Fig 1
Fig 2
Fig 3

PLATE I

DESCRIPTION OF APPARATUS (CF. PLATE I)

I. Photo-recording System.

L–L′	Source of illumination.	*M–M′*	Mirrors.
C–C′	Condenser lenses.	*N–N′*	Microscopes in string galvanometer.
Sl	Adjustable slit.		
P	Projection lens.	*K*	Photokymograph.

II. Fiber Circuit.

F	Fibers.		
A	Amplifier tube.	*G*	Mirror galvanometer.
B	Battery—circuit through fibers.	G^2	Standardizing galvanometer[3]
B′	A-battery—radio amplification.	*Ch*	Circuit changer.
B^2	B-battery—radio amplification.	*S*	Standardizing switch.
R	Resistance—filament control.	*Mf*	Condenser.

III. Galvanic Skin Reflex Circuit.

E–E′	Zinc electrodes.	R^1	Resistance for throwing B^3 current into outer circuit.
G′	String galvanometer.		
B^3	Battery for constant current.	R^2	Standardizing resistance.
R^3	Protection resistance.		

S′ Mercury-cup switch short-circuiting B^3, operated by wheel of photokymograph.

IV. Dry Air Supply.

Sp	Spirometer.	*St*	Stop-cock with regulating arm.
W–W′	Weights.		
T–T′	Tubes to center of moisture detector.	$CaCl_2$	Calcium chloride tube.

V. Miscellaneous.

Pn	Marey tambour for pneumograph.
Sg	Signal markers for subject and experimenter.
J	Jacquet chronoscope.

FIGS. 1, 2, AND 3. *Moisture sensitive element.*

f	Fibers covered with $CaCl^2$.
zn	Zinc plate electrode.
t–t′	Tubes to center of moisture detector.
g–g′	Tubes to center of moisture detector.
d–d	Brass plates connecting with ends of fibers.
e–e	Binding posts connecting with brass plates.
i	Binding post connecting with zinc plate.
j	Bakelite cover over fibers.
c	Air chamber next to skin.
h	Passage from air chamber to fibers

In order to eliminate the possibility that variations in the temperature of the skin might be an active factor in determining the changes in the conductivity of the fibers we tested the apparatus by moving it along an aluminum bar maintained by water baths at temperatures of 20° and 50° C. at the respective ends. No difference in the deflection at the two temperatures could be noted.

For measuring the galvanic skin reflex a Hindle model of the Einthoven string galvanometer, G', with the standard photokymograph, K, is employed (Plate I). For the moisture records a d'Arsonval mirror galvanometer, G, is caused to project the image of a slit of light, Sl, upon the above-mentioned photokymograph. The period of the latter galvanometer is decreased to 0.1 sec by using a relatively heavy wire suspension for the swinging coil. The lowered sensitivity of the instrument is then overcome by increasing the magnitude of the electrical changes by one step of radio amplification.

The electrical connections for the string galvanometer are of the standard type and are schematically presented as the "G.S.R. Circuit" in Plate I. The connections for the d'Arsonval galvanometer and for the radio amplification are represented by the "Fiber Circuit," Plate I.

A Jacquet chronoscope, J, interrupts the beam of light from the string galvanometer at second intervals, and, at the speed used for the photokymograph, makes lines on the film approximately one-fourth inch apart.[6]

The magnetic signal markers, Sg, operated by a key or a string,[7] indicate on the film, (1) the time the experimenter gives the stimulus and, (2) the beginning and the duration of certain sensory experiences of the subject.

In order that both E.M.F. and resistance changes in the skin may be accurately determined an E.M.F. of known potential is introduced into the circuit at 1½-sec intervals. For this purpose a mercury cup switch, S', operated by cams on the large wheel of the photokymograph is employed. Since the amplitude of the movement of the string of the galvanometer is very small compared with its length, we demonstrated that, with only a negligible error, the deflections by a constant E.M.F. vary inversely as the total resistance of the circuit. Further, we have proved by test that, with resistance constant, the fluctuations are directly proportional to the E.M.F.

Before the beginning of a test the apparatus is adjusted so that a known potential difference or E.M.F. acting against a known resistance produces a measured deflection. In order to determine the variations in the resistance of the subject we may employ Ohm's law, $\frac{E}{I \times R} = \text{constant}$,

$$\text{in the equation } \frac{E}{I(R+r)} = \frac{E_0}{I_0(R_0+r)}$$

[6] This speed was doubled in some of the later sittings.

[7] The string was employed in most cases because its use produces no induction or radiation effects upon the radio amplifier.

where E_s = the standardizing E.M.F.
R_s = the standardizing resistance
I_s = the current (deflection) with standard R_s and E_s. (The deflection is proportional to the current passing through the string and the deflection in cm is in each case substituted for I)
r = the resistance of the apparatus, especially that of the string
E = the potential under conditions of measurement
R = the resistance under conditions of measurement
I = the deflection under conditions of measurement.

In the case of the record shown in Fig. 4, the standardizing units measuring the sensitivity of the galvanometer may be substituted in the above equation giving the following:

$$\frac{E}{I(R+r)} = \frac{10 \text{ mv}}{7.6 \text{ cm } (7{,}300 \text{ ohms} + 2{,}700 \text{ ohms})}.$$

In order to measure the R of the subject an E.M.F. of 10 mv was impressed upon the subject and the amount of deflection of the standardized galvanometer determined. The deflection in the case of the B peak of Fig. 4 is approximately 3.2 cm. These conditions of measurement may be substituted in the equation leaving but one unknown quantity, R.

$$\frac{10 \text{ mv}}{3.2 \text{ cm } (R + 2{,}700 \text{ ohms})} = \frac{10 \text{ mv}}{7.6 \text{ cm } (7{,}300 \text{ ohms} + 2{,}700 \text{ ohms})}$$

R = 21,050 ohms.

It is assumed that no apparent increase in the subject's resistance has occurred due to the introduction of the standardizing E.M.F. It is true that slight indications of polarization phenomena are to be found in the very small reflex movement of the string which occurs during the first tenth of a second following each deflection. The electrical current producing the standardizing deflections is very small (10 millivolts) and the counter E.M.F. generated by it is correspondingly minute. No measurable difference in the amount of deflection accompanies a sudden reversal of the polarity of the standardizing E.M.F. This is true both when the standardizing current is such that the reversal renders it like in sign and when the change makes it opposite in sign to the current from the subject which is already present. Any polarization effect which is an influence on our records is a comparatively constant factor and does not appreciably affect the relative standing of the measurements.

To measure the E.M.F. of the subject the deflection caused by him is compared with that produced by a standard E.M.F. under the same conditions of resistance. The E.M.F. of 10 mv is impressed upon the subject and produces a momentary change in the deflection already present. In the case of peak B, Fig. 4, the subject's deflection is approximately 5.2 cm. The 10 mv deflection is 3.2 cm as before, and these two known quantities are now employed as standards in the equation. The resistances $(R_s + r)$ and $(R + r)$ are identical and cancel.

$$\frac{E}{5.2 \text{ cm } (R + r)} = \frac{10 \text{ mv}}{3.2 \text{ cm } (R_s + r)}$$

E = 16.25 mv.

The subject is seated in a chair, the back of which is turned toward the apparatus and the experimenter. Before

beginning a test of the correlation of the moisture changes with the galvanic skin reflex, moisture records are taken from various parts of the body, as for instance from the palm, the wrist, the forearm, the upper arm, etc., for the purpose of finding a position which gives a maximum of moisture change and another which shows practically none at all. The moisture-detecting electrode is then attached to the region giving the maximal fluctuation and the other electrode is applied to the part showing little or none. By this procedure a potential difference developed as the result of moisture changes in the neighborhood of one electrode is not counteracted by a similar potential difference developed at the other electrode through which the circuit is completed.

A routine procedure is followed. The lights are turned on the recording apparatus. Readings are taken of room temperature. The current flowing through the radio tube and impressed on the fibers is adjusted to a uniform magnitude. The tension of the string of the Hindle galvanometer is standardized. The image of the slit of light is adjusted to the photokymograph. Skin areas of maximal and minimal moisture change are determined, and the proper electrode is applied to each. The subject is given a string by which to indicate certain sensory changes to be described later. Normal records are taken, and following these we secure the records showing the effects of various forms of excitation. The subject is allowed after each reaction to return to a state of relative inactivity before the giving of another stimulus.

The stimuli employed are such as a light slap on the cheek, clapping the hands close to the subject's ear, slamming boards together, a flash of light in the eyes, tickling the back of the neck, a pin prick, and odors of valerianic acid, propionic acid, rose geranium and lavender. The voluntary or involuntary laugh, cough, or sigh of the subject is found to have an effect. No significant differences can be noted between the changes following the various types of excitation.

The subjects are graduate students in the Department of Psychology of the University of Chicago. Results from 30 persons are incorporated in this report.

A schematic full-sized copy of the record for one typical reaction is shown in Fig. 4. The record shows:

I. Electrical changes:

1. The galvanic skin reflex by the white broken line.
   (*a*)-Deflection; the short negative (downward) fluctuation terminating at peak *A*.
   (*b*)-Deflection; the large positive deflection beginning at peak *A* and terminating at peak *B*. (Where the initial condition of the moisture secreting region is negative the opposition between E.M.F. and effects of decreased resistance may result in no deflection or in a deflection in the direction of the (*c*)-change.)
   (*c*)-Deflection; the second negative deflection beginning at peak *B* and terminating at peak *C*.
2. Deflections of the G.S.R. line caused by the introduction of 10 mv constant E.M.F.,—a line consisting of short white marks corresponding to the breaks in the G.S.R. line.
3. Zero potential (the straight black line near the base of the record).
4. Resistance, by the curves plotted with broken lines. (The dotted portions are interpolated. A rise in the curve indicates increased conductivity.)
5. E.M.F. by the continuous line curve. (It is plotted from points indicated by the nodes.)

II. Moisture changes:

6. Fluctuations caused by moisture changes, by the black line.

III. Sensory changes:

7. Cutaneous sensations by a white line 2.5 cm from the top of the record.

IV. Miscellaneous:

8. Stimulus, by a short white mark 1.6 cm from the top of the record.
9. Time in seconds, by the fine vertical lines. (White in the original.)
10. Respiration, by the irregular white line at the bottom of the records. (Movement upward indicates inspiration.)

The Relation of the Secretory to the Electrical Changes

The relation between the moisture changes and the electrical phenomena will be presented in as brief a statement as possible, along with a very few generalizations. A more extended theoretical discussion will be given in another article after we have had an opportunity to study the electrical changes under other experimental conditions.

A description of the method by which we obtain records of both E.M.F. and resistance changes by the introduction

of a known potential at short intervals has been given. The care exercised in attaching the moisture-detecting electrode to an area showing wide moisture fluctuations and the other to

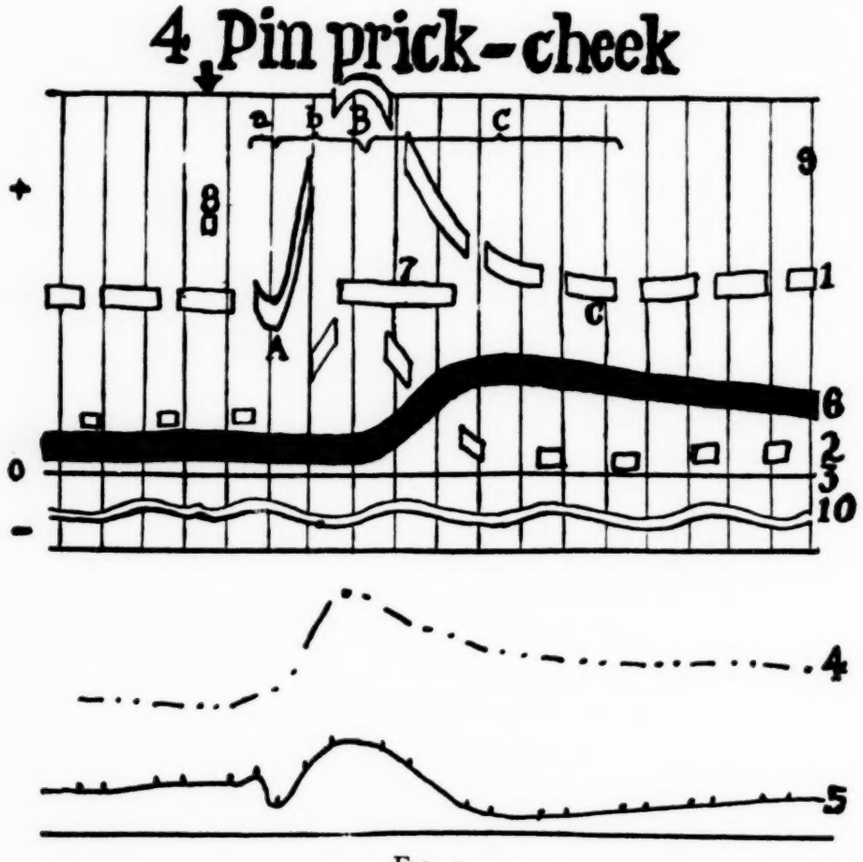

FIG. 4

a place showing none at all guarantees that, in so far as moisture may be a factor, the electrical changes are a function of the variations chiefly under one electrode.[8] The relative simplicity and uniformity of the curves obtained in this investigation as compared with those secured in some of our earlier studies where both electrodes were attached to secreting surfaces of the skin is some indication of the advantage of the procedure.

[8] In most cases the palm was the region of greatest moisture secretion. The middle of the posterior surface of the upper arm was found to be rather uniformly free from moisture changes. Instead of an electrode on a non-secreting area of the epidermis we have also tried the method of inserting a non-polarizable electrode in the subject's mouth, with similar results as to the form of the curve. A. D. Waller (*Proc. Roy. Soc.*, 1918, **90**, 215) advocated this latter procedure because the mucous surfaces manifest no electrical changes corresponding to the G.S.R. The greater conductivity of the mouth as compared with the skin in a non-secreting region is a point in its favor.

The succession of events in Fig. 4 is typical. It is as follows, in the order of occurrence:

I. Temporal relation of events in Fig. 4. (Time is measured from the moment of stimulation.)

1. Normal record; indicates a state of relative inactivity. (Palm is generally positive under our conditions by 10 to 25 millivolts.)	
2. Stimulus	0.0 sec
3. Beginning of "*A*" deflection (palm increasingly negative)	1.2 sec
4. Peak "*A*"—beginning of deflection "*B*"	1.8 sec
5. Beginning of moisture change	3.1 sec
6. Beginning of sensory experience	3.2 sec
7. Peak "*B*" of electrical change	3.7 sec
8. Termination of sensory experience	6.0 sec
9. Peak of moisture change—point where moisture production markedly decreases	7.2 sec
10. Peak of "*C*" negative electrical change (sometimes this appears to be merely a return to normal)	11.0 sec
11. Return to normal—the new level may be different from that preceding the reaction	22.0 sec

II. Magnitude of changes indicated in Fig. 4. (See method of calculation, page 203)

1. Normal—state just prior to stimulation.	
Amplitude of subject's deflection [9]	2.3 cm
Amplitude of 10 mv deflection	1.7 cm
E.M.F. (palm)	+13.5 mv
Resistance	42,000.0 ohms
2. "*A*" deflection	
Amplitude of subject's deflection	1.9 cm
Amplitude of 10 mv deflection [10]	?
E.M.F.[10]	?
Resistance [10]	?
"*B*" deflection peak	
Amplitude of subject's deflection [11]	5.2 cm
Amplitude of 10 mv deflection	3.2 cm
E.M.F.	16.3 mv
Resistance	21,050.0 ohms
"*C*" deflection peak	
Amplitude of subject's deflection [11]	2.5 cm
Amplitude of 10 mv deflection	2.4 cm
E.M.F.	10.4 mv
Resistance	28,920.0 ohms

[9] Measured from point of zero potential.

[10] The 10 mv deflection did not occur during the "*A*" deflection in this instance and consequently we have no basis for calculation. Other records indicate no change in resistance and an increasingly negative E.M.F. during this change.

[11] Measured from point of zero potential.

TABLE I

TEMPORAL RELATION OF MOISTURE AND ELECTRICAL CHANGE
Showing approximation of the beginning and peak of the moisture curve to peaks *B* and *C* respectively

Subj.	*N*	Latent Time *A*	Latent Time *B*	Latent Time Moisture Minus .2 sec Corr'n	Peak *B*	Peak Moisture Deflection Minus .5 sec Corr'n	Peak *C* Deflection
W....	11	1.4 A.D. 0.25	2.0 A.D. 0.16	3.1 A.D. 0.26	3.9 A.D. 0.29	5.9 A.D. 0.81	10.0 A.D. 1.15
W....	18	*	1.8 A.D. 0.12	3.3 A.D. 0.25	3.5 A.D. 0.21	5.8 A.D. 0.37	8.7 A.D. 0.77
V.....	7	*	1.9 A.D. 0.80	2.7 A.D. 0.29	3.4 A.D. 0.56	7.1 A.D. 0.55	8.4 A.D. 0.46
Rr....	7	*	2.0 A.D. 0.29	2.7 A.D. 0.29	4.1 A.D. 0.29	2.5 A.D. 0.49	8.8 A.D. 0.64
Rp...	9	1.4 A.D. 0.08	1.9 A.D. 0.11	2.5 A.D. 0.24	3.7 A.D. 0.25	5.7 A.D. 0.40	7.3 A.D. 0.19
Rh...	12	*	1.4 A.D. 0.14	2.1 A.D. 0.14	3.0 A.D. 0.14	4.4 A.D. 0.38	7.2 A.D. 0.48

* Not clearly evident in all curves.

The average times for each event in the record of electrical and moisture changes is shown by Table I. It will be seen that the *B* electrical change begins about one second before the indication of moisture at the surface. The peak of the *B* deflection occurs only a fraction of a second after the appearance of surface moisture. The maximum of secretion occurs about two seconds after the peak of the *B* change and two seconds before the peak of the *C* deflection.

Further demonstration of the relation of the electrical to the moisture changes is obtained by the method of correlation. This is rendered difficult, however, by the fact that in the majority of our cases only a few readings could be secured at a sitting and that the state of the subject and the condition of the moisture apparatus vary from day to day. To compensate as far as possible for changes occurring between the two sittings which are the basis for the following correlations the ranges of the corresponding distributions of data on each measure were rendered equal by multiplying one of them by an appropriate factor before pooling the data. The following correlations of electrical with moisture variations were determined for subject W:

($N = 29$)

	r =
A. Duration of moisture change (initial rise, to peak)	
1. With duration of "*B*" electrical deflection	.55 ± .09
2. With amplitude of "*B*" electrical deflection	.67 ± .07
3. With duration of "*C*" electrical deflection	.46 ± .10
4. With amplitude of "*C*" electrical deflection measured from "*B*" peak	.69 ± .07
5. With E.M.F. "*B*" change from normal	.38 ± .11
6. With E.M.F. "*C*" change from "*B*"	.45 ± .10
7. With resistance "*B*" change from normal	.66 ± .07
8. With resistance "*C*" change from "*B*"	.18 ± .12
B. Amplitude of moisture change	
1. With duration of "*B*" electrical deflection	.52 ± .09
2. With amplitude of "*B*" electrical deflection	.73 ± .06
3. With duration of "*C*" electrical deflection	.54 ± .09
4. With amplitude of "*C*" electrical deflection measured from "*B*" peak	.81 ± .04
5. With E.M.F. "*B*" change from normal	.47 ± .10
6. With E.M.F. "*C*" change from "*B*"	.47 ± .10
7. With resistance "*B*" change from normal	.45 ± .10
8. With resistance "*C*" change from "*B*"	.17 ± .12

TABLE II

THE RELATION OF MOISTURE TO ELECTRICAL CHANGE

Shows that an increase in moisture change is accompanied by increased magnitude of *B* and *C* deflections

Subj.	By Thirds (Ranking forMoisture Deflection)	*N*	Moisture Change		Electrical Change							
					B Change				*C* Change from *B*			
			Deflection (cm)	Duration (sec)	Duration (sec)	Deflection (cm)	E.M.F. Change (mv)	Res. Decrease (ohms)	Duration (sec)	Deflection (cm)	E.M.F. Change (mv)	Res. Increase (ohms)
W....	Low.....	19	0.53	2.20	1.60	0.93	+0.45	−13648	3.01	−0.70	−1.55	8335
	Middle.....		0.80	2.41	1.74	1.20	−1.25	−16355	3.07	−0.88	−4.25	6260
	High.....		1.32	2.92	1.72	1.25	+2.27	−20530	3.65	−1.18	−5.50	7970
W....	Low.....	11	0.42	2.42	1.62	1.60	−0.40	−14500	5.18	−1.50	−1.22	8250
	Middle.....		0.78	2.88	1.90	2.22	+0.40	−16200	6.12	−1.88	−3.16	6475
	High.....		1.20	4.90	2.10	3.00	+2.00	−18865	7.77	−2.66	−4.60	7970
V.....	Low.....	7	1.40	4.45	2.05	0.25	+1.31	− 7660	6.85	−0.70	−2.00	4510
	Middle.....		1.60	5.27	1.47	0.33	+2.38	−10140	6.20	−0.83	−2.43	4410
	High.....		2.25	3.30	.70	0.45	+1.76	− 5140	6.85	−1.10	−4.75	2870
Rr....	Low.....	7	2.25	4.80	1.95	1.95	+6.18	−25470	9.05	− .10	−0.71	9620
	Middle.....		2.70	4.93	2.00	2.00	+9.84	−20773	8.70	−2.66	−1.84	6940
	High.....		4.15	5.50	2.45	2.45	+7.96	−27350	8.75	−2.50	−1.75	10450
Rp...	Low.....	9	0.50	3.03	2.10	0.45	+3.86	− 4100	3.90	−0.34	−4.84	4200
	Middle.....		0.67	3.50	2.47	0.58	+3.52	− 8400	3.83	−0.54	−4.48	3683
	High.....		0.90	4.00	2.40	0.82	+5.98	− 9040	3.43	−0.65	−5.40	3740
Rh...	Low.....	12	0.98	2.45	1.70	1.06	−1.06	−14720	5.57	−3.26	−1.50	7620
	Middle.....		1.80	2.55	1.63	1.15	−0.32	−11185	4.20	−3.41	−1.74	7942
	High.....		2.02	3.03	1.44	1.32	+0.08	—13363	4.40	−3.43	−2.15	8685

That other subjects manifested the same relation of electrical to moisture changes, although our data are insufficient for a valid correlation, is evident if we rank the results according to the magnitude of the moisture deflection and compare averages for the upper, middle and lower thirds. Table II gives the averages of the respective divisions of the data for the subjects on whom we obtained controlled simultaneous records of the two phenomena. It will be noted that in all cases the increase in the amplitude of the moisture change is correlated with a corresponding increase in the amplitude of the "*B*" deflection, and that this relation also holds in almost every instance for the "*C*" deflection.

Our statement regarding the nature of the processes giving rise to the various electrical changes must be brief and entirely tentative, pending tests under certain conditions suggested by the present study. We shall first state the nature of the electrical changes.

The "*A*" deflection, when present, is characterized by an increasingly negative relative potential of the secreting surface, and by no detectable change in bodily resistance.

The "*B*" deflection gives evidence of a rapidly decreasing resistance of the body, the conductivity of which reaches a maximum at peak *B*. There is evidence of an increasing positive potential of the secreting area during the first part, and of a decreasing positive (or increasing negative) relative potential during the latter part of the *B* deflection.

The "*C*" deflection gives evidence of a rapidly increasing resistance of the body and of an increasing negative relative potential of the moisture-secreting region.

The potential change characteristic of the *A* deflection is most difficult of explanation. This deflection is not apparent in all of the curves and we are reserving judgment as to its cause until opportunity for further study. It may be an artifact.

The reduction of resistance characteristic of the *B* deflection is probably due to the increased permeability of the tissues of the moisture-secreting area.[12]

[12] According to Dr. Ralph S. Lillie in his comprehensive book on *Protoplasmic Action and Nervous Action* (Univ. of Chicago Press) the normal vital processes, whether

The potential changes are probably a function, first, of depolarization and the transfusion of liquid through the membranes, and second, of the change in relative ion concentration due to the change in relative moisture under the two electrodes.[13] It is significant that the increase in relative negative potential of the moisture-secreting region begins simultaneously with the appearance of detectable moisture at the surface of the skin.

The increase in resistance which is a factor in the *C* deflection is the result of the gradual recovery of the original state of semi-permeability by the body tissues. This change is indicated by the decrease in the amplitude of the 10 mv deflection which continues with decreasing rapidity until the relatively high resistance obtains which characterizes the state of rest. The accompanying increase in the relative negativity of the moisture-secreting region, as previously stated, is probably the result of the differences in moisture and consequently of ion concentration in the regions of the two electrodes.

The relation of the moisture deflection to the *C* and, in a lesser degree, to the *B* electrical deflections is in the case of the subject on whom we have sufficient data for a correlation a function neither of E.M.F. nor of the resistance changes solely, but of the combined influence of the two. Neither the E.M.F. nor the resistance change correlates so

neural, muscular or glandular, all involve the temporary breakdown of the semi-permeable membranes surrounding the cells. This rupture of the protoplasmic boundaries may be initiated by physical contacts, chemical conditions, or electrical changes. Lillie says (page 346); "If during the local stimulation-process there is in fact a temporary breakdown or dissolution of the protoplasmic surface-film, a temporary increase of permeability to water-soluble diffusible substances should be associated with stimulation." Again, on page 374; "In the higher animals the phenomena accompanying the secretion of gland cells, especially those under nervous control, show many resemblances to those just described. . . . There is the same loss of water and dissolved material from the cell, the same electromotor variation, and the same gradual recovery. The variations in the permeability of the mammalian kidney cells under the influence of fear, excitement, or other abnormal emotional or nervous conditions also suggest that in these cells stimulation is associated with increased permeability; similar evidence is furnished by sweat glands."

[13] In measurements of electrical changes where liquid electrodes are employed the moisture secreted would be readily diffused through the liquid of the electrode, and therefore no potential differences due to this second cause would be noted.

highly with the moisture deflection as does the "current" change $\left(\text{Current} = \frac{\text{E.M.F.}}{\text{resistance}}\right)$. This is evident in the following table of coefficients of correlation (r) of moisture deflection with electrical change.

	B Electrical Change	*C* Electrical Change
E.M.F.	0.47 ± .10	.047 ± .10
resistance	0.45 ± .10	0.17 ± .12
current	0.65 ± .07	0.81 ± .04

From this it seems justifiable to presume that had an external current been employed, since the current would have then been inversely proportional to the resistance (barring polarization effects), the deflections would have shown the same relatively low correlation manifested by the resistance change. Of course we are justified in this generalization only as regards this subject and the type of electrode here employed. We are now endeavoring to accumulate more evidence on this important point.

So far as tested, the regions of greatest moisture secretion correspond roughly to those described by Leva [14] and indicated in his charts. Nevertheless there seem to be great individual differences in the distribution of the secretory activities. Especially has this been noted in our study, as regards the activity of the sweat glands in the palm of the hand and wrist. To our surprise we found subjects, seemingly normal in every other way, who showed practically no secretory changes in the palm of the hand, but from whom perfectly typical records could be secured by applying the moisture-detecting electrode to the wrist. This suggests the importance of a study of the entire skin surface of a large number of individuals before we are to know what constitutes a 'normal' distribution.

Sensory Phenomena

During our early experimentation with the galvanic skin reflex the writer noted certain cutaneous sensations accompanying the electrical changes. These were of sufficient

[14] *Op. cit.*

definiteness to enable him, when serving as subject, to indicate with considerable accuracy whether an electrical fluctuation had occurred. The only reference to such sensations in connection with the galvanic skin reflex discovered in the literature is one by Gildemeister [15] in which he refers to 'gooseflesh,' 'hot and cold,' 'shuddering,' and 'pressure' sensations in the skin as frequent accompaniments of the galvanic phenomena.[16] He reported no controlled experimental study.

The method of recording the sensory changes has already been described. Verbal reports were obtained from the subjects during the preliminary tests and at intervals during the course of the experiment. The subject was first asked to note any sensory changes following the stimulus other than those from the sense organs directly affected. If he reported sensory changes in the skin he was further questioned about their location on the body and the time of their occurrence relative to the moment of feeling the stimulus. Care was taken that he should volunteer the specific nature of these phenomena and that the experimenter by questioning should not suggest their character. If he could sense them and note their place in the arm he was asked if he could indicate by pulling a string the time when a change occurred in the region of the moisture-recording electrode. The definiteness of the experience which was the basis for this response is in some measure indicated by the close temporal relation of the reported sensory phenomena to certain of the recorded physiological changes as shown by Table III. The details of this correlation will be discussed after a brief sampling of the subjects' reports.

Subject W: I felt a swelling in the hand and arm and a sort of rigidity. I have the same feelings as when angry. There is a burning sensation over the surface of the body, especially the face. There is something that moves downward into the hand; a pricking, stinging, heating sensation comes to the surface of the skin, reaches a climax slowly a second or two after the stimulus, and then fades away. The arm gets it after the sensation is felt in the body. It is felt also around the feet. It comes to the head first. When the hand is struck it seems to start there and to spread up

[15] M. Gildemeister, *Arch. f. d. ges. Physiol.*, 1922–23, **19**, 432–438.

[16] A good discussion of the sensory phenomena, though not in relation to the G.S.R., is to be found in L. R. Mueller, *Die Lebensnerven*, 356–410.

to the face. When the leg is struck it seems to start there. This is something I never noticed before. It is a new sensation to me.

Subject T: I note a decided difference in the sensation according to the severity of the stimulus. When struck hard there is a decided tingling in the arm and hands which seems to recur in waves after it reaches the hand. When I am struck more lightly there is a feeling of fullness that spreads down the arm and seems to flow out through the hand. In one case I could tell when the tingling went under the wrist electrode and later when it went under that on the palm. I can feel these sensations in any part of the body to which I pay attention. The sensations are similar to those from cutting off the circulation. It feels as if a part of the body were coming out from the state of being "asleep."

Subject Ba: I could feel visceral sensations spreading internally. Something like a shiver spreads from the ears down the back and side. The cutaneous feelings of 'shivering' accompanied the visceral experiences, but the visceral do not always follow the cutaneous. I felt tingling reverberations in response to the slap and the loud noise. This occurred in spite of the fact that I expected the stimuli. The odors at first produced cutaneous and mild visceral sensations persisting for one-half minute or so. The cutaneous sensations spread from above downward. The side which is stimulated reacts most quickly. The sensation gets to the fingers first on the side stimulated. It gets to both feet about the same time. There seems to be a cumulative effect when the stimuli occur closer than 10 seconds apart. The voluntary laugh produces large cutaneous but little visceral response.

Subject B: Following the stimulus I feel something like a chill down the back. [After being slapped harder] Oh, yes, I get a tingling down the arm, also. The cough produces a feeling of chill in the skin. It seems to spread down over the arm. It is like hitting the funny bone. When you hit the right arm it spreads up the arm and also down to the fingers; it does not go to the other side but stops at the neck and shoulder.

Subject S: A wave travels down the arm, passes the electrode on the upper arm and seems to reverberate in the hand and fingers—like thunder dying away. The sensations are like gooseflesh. The tingling starts with a visceral reaction. Pressure on the diaphragm upward precedes the gooseflesh. It seems to go down the arm from the shoulder and to be more noticeable at the extremities than in the body. I had noticed the gooseflesh before, but not the visceral reaction which precedes. There is no sudden break in the sensation when I release the string. I am tempted to pull the string a number of times afterward. The experience seems to be coming back. [This agrees with the record. The subject often showed one or more rises in the moisture curve following the first.]

Subject V: I get a warm thrill inside like taking a drink of wine. Tingling sensations went down from the head. There are scattered diffuse sensations around the head like a very mild shock. It is similar to the state of being frightened, when the hair stands on end. It seems to begin around the ears and to go down toward the stomach. The stomach feels heavy. It is like a mild stimulus from many needles. When the boards were slammed no "needles" were felt but the sensation went immediately toward the stomach. A second wave started in the stomach which had more of the "needle" effect than the first. It spread out from the stomach in many directions.

The reports of all subjects were essentially similar to those given in the excerpts already cited. We have summarized

the reports of twenty-six subjects of this experiment in Table III.

TABLE III

SUBJECTS' REPORTS

Shows the frequency of the various sensory experiences

Subj.	Kind of Sensory Experience						Spatial-temporal Course of Sensory Changes	
	Tingling	Warmth	Shiver: Chill	Gooseflesh	Fullness: Swelling	Visceral Sensations	Begins Generally at Head, Goes Down	Often Recurs in Waves
T.	*	*			*		*	
Rh.	*	*				*	*	
Ba.	*		*			*	*	*
Sn.	*	*	*			*	*	
B.	*	*	*				*	
Bn.		*				*	*	
W.	*	*			*		*	
O.	*					*	*	
Rr.	*	*					*	
G.		*					*	
Sp.	*			*		*	*	*
Rp.	*	*					*	
V.	*	*				*	*	*
K.	*	*						
J.	*	*					*	
Br.	*		*				*	
C.		*	*				*	
Pt.	*	*	*				*	
Bal.	*	*	*			*	*	
Sw.	*						*	
St.	*	*				*	*	
Bk.	*	*	*				*	
Pa.	*	*	*			*	*	*
M.		*				*	*	
P.	*	*				*	*	
Co.			*			*		
% of Subjs.	81%	77%	38%	4%	8%	50%	92%	15%

The sensory phenomena commonly noted are those of tingling, of warmth, of shivering, and of distension of the various parts of the body, especially of the arms and hands. Visceral sensations are frequently present. These effects may be reported singly or in combination. Subjects often referred to differences in the sensory experiences following the various stimuli;

but there seems to be no unanimity as to the nature of these differences.

The sensory phenomena were observed in most instances to begin in the region of the head, generally about the ears, and to spread downward over the arms and trunk. Sometimes, however, the effects radiated outward from the chest. When sense organs other than those located in the head were stimulated, *i.e.* when the arms, trunk, or legs were struck, the subjects often reported a wave of tingling, warmth, or pressure, radiating outward from the point of stimulation. This fact would lead us to anticipate a difference in the latent time of the sensory, secretory, and electrical changes when the stimulus was applied to the body at varying distances from the position of the recording electrode. This assumption was tested in the case of subjects Ba, S, T, and V, and no significant differences were noted. The large variability in reaction time due to other factors probably accounts for the obscuring of the effects. A similar test was made by keeping the point of stimulation constant and applying the moisture-sensitive electrode to various regions of the body. Here, again, no significant difference in latent time was evident; although marked variations were to be found in the magnitude of the reaction for the various positions. As already indicated the regions of the body vary markedly in the amount of cutaneous secretion.

Examination of the records shows that the beginning of the experience coincides closely with the beginning of the moisture change, and that its termination bears a definite relation to the peak of the curve, the point where the production of moisture decreases. A similar relation exists between the beginning of the sensory phenomena and the peak *B* of the electrical change. Table IV gives records from sittings with subjects in which a sufficient number of sensory and physiological reactions occurred to be significant. It will be noted that the intervals recorded are so short as to suggest a causal relation between the two phenomena. Especially is this true when the difficulty of observing the fleeting sensory changes is taken into consideration.

TABLE IV

TEMPORAL RELATION OF SENSORY TO SECRETORY AND ELECTRICAL CHANGES

Shows the approximate simultaneity of the sensory experience and the physiological change

Subject	*N*	Sec from Beginning of Secretion (Corrected −.2 sec) to Beginning of Sensation	Sec from Peak of *B* Electrical Change to Beginning of Sensation	Sec from Peak of Moisture Change (Corrected −.5 sec) to End of Sensation
W.....	11	+0.61 A.D. 0.65	−0.04 A.D. 0.54	+0.21 A.D. 0.48
W.....	18	+0.79 A.D. 0.40	+0.52 A.D. 0.46	+0.68 A.D. 0.73
T.....	14	−0.33 A.D. 0.48	−0.25 A.D. 0.30	+0.10 A.D. 0.90
Bw....	7	−0.99 A.D. 0.56	−0.46 A.D. 0.63	−0.66 A.D. 0.89
Bw....	14	−0.89 A.D. 0.67	No record	+1.11 A.D. 1.20
V.....	8	+0.10 A.D. 0.45	+0.51 A.D. 0.76	−2.63 A.D. 1.28
V.....	15	No record	−0.66 A.D. 0.68	No record
P.....	10	−0.38 A.D. 0.58	No record	+2.33 A.D. 1.13
S.....	11	+0.88 A.D. 0.65	No record	+0.50 A.D. 0.98

The duration of the sensory change seems to bear a definite relation to the severity of the stimulus and to the magnitude of the physiological changes. According to the testimony of several of the subjects the duration of the sensory changes is also roughly proportional to the intensity of the total subjective disturbance. Of course there is no one-to-one relation between the severity of the objective stimulus and the degree of feeling on the part of the subject; and yet we might expect these two variables to show a fairly high correlation.

In the case of one subject we attempted to demonstrate by a somewhat crude method a relation between the intensity of the stimulus, the duration of the sensory experience, and the magnitude and duration of the recorded physiological changes. For one sitting with Subj. W, the most frequently used stimulus, the slap on the face, was roughly graded according to the estimate of the experimenter into three degrees of severity, light, moderate and hard. The relation between the strength of the stimulus and the subject's reactions in this test are given in Table V for whatever suggestive value they may have.

Though the results are tentatively offered, the fact that several of the subjects declared that the duration of the sensory changes seemed to be determined by the intensity of

the subjective experience seems significant. In the case of the more disturbing reactions the sensory phenomena not only lasted longer but in many subjects they tended to recur in waves. This fact suggests that the duration of the sensory change, as indicated by the subjects' pulling of a string, may constitute a good criterion of the intensity of a subject's emotional or affective state.

TABLE V

RELATION OF INTENSITY OF STIMULUS TO SENSORY AND PHYSIOLOGICAL CHANGES

Stimulus = Slap	Sensory Change	Moisture Change		Electrical Change		Amplitude $B + C$ Change (cm)
	Duration Sensory Change (sec)	Duration (sec)	Amplitude (cm)	Amplitude B Change (cm)	Amplitude C Change (cm)	
Light ($N = 5$)...	1.2 A.D. .7	2.1 A. D. .2	0.50 A.D. .2	1.00 A.D. .3	0.66 A.D. .1	1.66 A.D. .2
Moderate ($N = 3$)...	2.1 A.D. .9	2.2 A. D. .3	0.53 A.D. .2	0.96 A.D. .4	1.10 A.D. .4	2.06 A.D. .1
Hard ($N = 6$)...	2.2 A.D. .8	2.5 A. D. .3	0.81 A.D. .2	1.10 A.D. .3	1.17 A.D. .3	2.37 A.D. .3

With the above possibility in mind the correlation of the duration of the sensory changes with the duration and magnitude of the moisture and electrical variations is especially significant. It is further evidence of the relation of sensory experience to physiological processes. Correlations of moisture and electrical variations with the duration of the sensory change have been worked out for the data from two sittings (Subj. W) of 11 and of 18 reactions. No readjustment of the apparatus occurred during either sitting. The data from the two sets of records have been rendered comparable by the same method as used when showing the correlation of the electrical with the moisture phenomena; the same constants have been employed. In the case of the correlations which are starred, the raw data of the two sittings were already comparable and no modification was necessary.

A. Duration of sensory phenomena correlated with moisture deflection
1. With duration of moisture fluctuation ..... 0.76 ± .05 *
2. With amplitude of moisture fluctuation ..... 0.76 ± .05 *

B. Duration of sensory phenomena correlated with electrical deflection
1. With duration of *B* electrical change ..... 0.53 ± .09 *
2. With duration of *C* electrical change ..... 0.43 ± .10
2. With amplitude of *B* electrical change ..... 0.53 ± .09 *
With amplitude of *C* electrical change ..... 0.56 ± .09 *

C. Duration of sensory phenomena correlated with E.M.F. change
1. With E.M.F. *B* change from normal ..... 0.16 ± .12
2. With E.M.F. *C* change from *B* ..... 0.39 ± .10

D. Duration of sensory phenomena correlated with resistance change
1. With *B* resistance change from normal ..... 0.54 ± .09
2. With *C* resistance change from *B* ..... 0.08 ± .12

The data for subjects on whom a number of records of simultaneous sensory and physiological changes were secured have been ranked according to the duration of the sensory phenomena and divided into thirds. The averages of the upper, middle, and lower thirds are given in Table VI.

The physiological and psychological state of the subject was apparently of importance in determining the nature of the results. For instance, the observation of the sensory changes by the subject seemed to be most effective in the presence of a moderate amount of relaxation. This relaxed state was ordinarily secured without special instruction owing to the fact that after the attachment of the recording devices, the subject was directed to sit quietly and to be as comfortable as possible. The darkness of the room and the monotony of the procedure were also conducive to this condition. In some instances there was a specific request to relax. The importance of the reduced tension is evident in the case of subject Ba, who reported that, after he had served as a subject, he began to watch for the sensory experiences during his daily routine. He stated that he observed their presence in a condition of general bodily activity only when there was a severe sensory or emotional excitation; but that, when he allowed himself to relax, far-reaching effects were noticeable from even very moderate stimuli.

Subject T noted that sensory changes might even be *produced* by the process of relaxation, and he ascribes to

TABLE VI

THE RELATION OF THE DURATION OF THE SENSORY CHANGES TO THE PHYSIOLOGICAL PHENOMENA
(AVERAGES FROM DATA RANKED ACCORDING TO THE DURATION OF THE SENSORY EXPERIENCE)

Shows the duration of the sensory experience to be a function of the magnitude of the physiological change

Subject	*N*	Third (Ranked for Duration)	Sensory Experience	Moisture Change		Electrical Change			
						B Change		*C* Change	
			Duration	Duration	Amplitude	Duration	Deflection	Duration	Deflection
W	11	Low	1.28	2.53	0.58	1.60	1.98	5.95	1.70
		Middle	2.70	2.85	0.75	1.85	2.15	6.10	2.00
		High	3.58	4.83	1.08	2.17	2.67	6.77	2.40
W	18	Low	0.80	2.05	0.62	1.55	.80	2.75	0.70
		Middle	2.13	2.63	0.87	1.75	1.22	3.45	1.00
		High	3.38	2.89	1.25	1.78	1.33	3.69	1.10
V	15	Low	0.83	4.07	1.60	1.93	.62	6.73	0.58
		Middle	1.04	4.50	1.60	1.72	.76	6.30	0.45
		High	2.72	5.43	2.77	1.50	.76	6.60	0.88
Ba	15	Low	1.82	3.00	0.50	Subject's E.M.F.		2.32	0.52
		Middle	2.82	2.40	0.36	near zero. ∴		2.46	0.50
		High	5.42	3.27	0.77	no deflection		3.12	1.30
Bi	11	Low	2.55	6.08	2.70	No Electrical Record			
		Middle	4.32	6.75	3.12				
		High	8.77	7.37	5.70				
S	30	Low	2.41	4.02	0.85	No Electrical Record			
		Middle	3.57	5.17	1.22				
		High	5.71	5.31	1.67				
P	11	Low	4.08	2.65	1.00	No Electrical Record			
		Middle	5.03	2.00	1.43				
		High	5.63	3.20	1.90				

them an intense positive affective value. He reports his experience as follows:

"I discovered it after participation in the experiment, while attempting one night to obtain rest after a long period of strain. In an effort to reduce the tension of the whole body and of the shoulders and neck and jaw in particular, the relaxation of one set of muscles at a time was attempted. This had been quite generally effected, when I became aware of the pleasantness accompanying the relaxation of each muscle or set of muscles. For many minutes I then lay in bed simply indulging the soothing sensations which would sweep over my whole body with each new muscular relaxation. Qualitatively the experience is not unlike the feeling of chill which runs down the spine when a draft is felt on the back of the neck; but, whereas the chill is unpleasant, this sensation is luxuriously pleasant, and whereas that is confined to the spine, this spreads over the whole body. It seems to be distinctly sub-dermal. Originating at the point of relaxation it spreads in all directions. If made to originate in the abdominal region, it will spread toward the lower and upper regions simultaneously. Although it can be followed to the lips or to the toes it is easily most pleasant in the torso and in the facial regions. There is nothing of the pricking, stinging, or tingling sensation in the self-induced soothing experience incident to the relaxation.

Since this first experience I have found it a most effective means of soothing myself to sleep. I find that it does not require an actual relaxation to originate the sensory changes; just the thought of relieved tensions is sufficient. Of course this last may involve an incipient muscular reaction. The experience is not felt in any region which may be tense at the time; for example, when lying down, it is not experienced by that part of the body in contact with the bed. When sitting in the chair in the Psychological Laboratory the pressure of the feet on the door jamb inhibited its flow into the lower limbs."

As a test of the objective reality of these phenomena, Subj. T was asked to produce the effects of voluntary relaxation in the Laboratory with the apparatus attached to him, and to indicate by pulling a string the initiation and termination of each sensory experience in the region of the electrode. At first the same correspondence between sensory and physiological changes was obtained as characterizes the records following stimulation. As relaxation became more complete these objective changes were greatly reduced in amplitude until they were hardly noticeable. When the subject was again stimulated in a normal fashion the typical record was obtained. This result conforms to the outcome of an earlier study of the effects of activity and quiescence upon the electrical phenomena. These results are to be published under a separate title.

In this connection it is interesting to note that the frequent repetition of the same stimulus causes so little adaptation as

is evident in our experiments. It is true that both the secretory and the electrical changes tend to be reduced in magnitude toward the end of a sitting. This may be due in part (1) to the effects of increased relaxation, (2) to the influence of adaptation or growing indifference to the stimulus, (3) to the decreasing sensitivity of the apparatus, and (4) to polarization changes in the tissues resulting in the so-called "curve of rest." [17]

On the other hand, subjects built up an increasing susceptibility to the more severe stimuli, even to the point of getting frequent anticipatory reactions when no stimulus was given. These reactions could easily be observed by the experimenter, and questioning of the subject almost invariably elicited the response, "I thought you were about to strike me."

The sensory phenomena here studied seem to be characteristic of emotional states in general. Most subjects at the beginning of their series of reactions were inclined to describe changes in very vague, general terms rather than by reference to the specific experiences composing it. A common observation was, "I feel as I do when I am frightened" or "It's the same feeling I have when I am angry." In an experiment with the falling chair in which the victim was suddenly and without warning precipitated backward and downward to a horizontal position [18] the writer obtained reports from forty naïve subjects. Following the first experience with the drop, several recalled having noted some of the sensory phenomena described in this paper. One half of the number were fastened rigidly in the chair, the other half were free to struggle. The group of fastened subjects either suffered more pronounced sensory changes or were better able to observe those that took place than were those who were not fastened. This may be due to the fact that in the case of the subjects who were free to move in the chair sensory changes were

[17] David Wechsler, The measurement of emotional reactions, *Arch. of Psychol.*, 1925, **76**, 37 ff.

[18] For a description of the apparatus, see W. E. Blatz, The cardiac, respiratory, and electrical phenomena involved in the emotion of fear, this JOURNAL, 1925, **8**, 109–132.

obscured by the sensations from the gross bodily activity. This explanation may have its bearing on the previous observation that the phenomena are not ordinarily observed when the subject is in an active rather than in a relaxed condition. Table VII summarizes the reports.

TABLE VII

SENSATIONS FOLLOWING A SUDDEN UNEXPECTED FALL

Sensory Change	Non-fastened Subjects $N = 20$	Fastened Subjects $N = 20$	Total $N = 40$
Tingling in arms and hands	3	6	9
Tingling in legs and feet	2	4	6
Flushing of the face and neck	11	11	22
Sinking sensations in thorax and abdomen	11	16	27

Apparently the cutaneous sensory changes here described are observable under many different conditions of normal life. In our preliminary tests with widely varied stimuli we found that any comparatively sudden stimulus may produce the changes in general sensitivity which we have mentioned. Several subjects identified the experience with that which occurs when they have been "thrilled" by the climax of a lecture or of a musical selection, or by a cold shower. A few even noticed the phenomena accompanying defecation, micturition, and sexual excitement. One individual reported having noted these changes when in association with other persons, notably those whom he revered, and especially with those of the other sex.

Our results suggest very specific mechanisms giving rise to the various sensory changes. There is no occasion on the basis of the present study to assert, however, that the sensory phenomena involving tingling, warmth, and sense of 'fullness' of the various parts of the body are all, or even any one of them, due to moisture changes. We feel no more justified in such an assertion than in declaring that they are of electrical origin. There are other mechanisms in the skin activated along with sweat glands which may be even more effective in exciting the dermal receptors. It is possible, too, that an

effect upon the muscle spindles, due to changes in the tone of the muscle fibers, is a factor. An immediate problem for further investigation is the relation of the temperature, vasomotor, pilomotor, secretory, and tonus changes to the warmth, shivering, 'fullness,' tingling, and other sensory experiences. We believe that it is possible to analyze these complex sensory phenomena with reference to the specific processes involved in their excitation.

As previously indicated the so-called emotional effects reported in this article have been aroused under conditions of quite moderate excitation. The nature of the subjective reports and of the objective results, under varying degrees of stimulation, assures us that these same effects are present, though in exaggerated degree and perhaps with altered 'profile,' in cases of extreme emotional disturbance. Our results suggest that all stimuli, even when of moderate intensity, have an observable effect upon the sensory processes of the entire body, as well as a specific character attributable to the directly affected end-organ. This supports the view that one difference between the simpler sensory experiences and the 'emotion' lies in the relative intensity of the excitation of the directly stimulated receptors as compared with the activity of the indirectly aroused cutaneous and organic sense organs. In other words, every sensory experience may have its accompaniment of altered general sensitivity, which, under normal conditions, may pass unnoticed. The fact that it is unnoticed does not from our point of view lessen its importance in the total sensory configuration. In the case of emotion the exciting cause of the disturbance is drowned in the flood of these secondarily aroused processes. It seems to the author that there must be a more extended study of the simple reactions occurring under conditions of moderate excitation before we can hope successfully to analyze the almost cataclysmic disturbances characteristic of profound emotional states.

Summary

By way of summary we call attention

1. To the device by which continuous records of moisture change are secured. The many possible applications of this instrument need not be enumerated.

2. To the demonstrated correlation of changes in the galvanic skin reflex with moisture change.

3. To the fact that the galvanic skin reflex, when no external current is employed and when the leads are taken by means of moist but non-liquid electrodes, is a function of relatively independent E.M.F. and resistance changes.

4. To the evidence that the decreased resistance typical of the galvanic skin reflex is a function, just as are many other physiological changes, of the breakdown of the semi-permeable membranes of the body. It is not due to the mere presence of conductive moisture on the skin.

5. To the presence of general cutaneous sensory changes following in the wake of quite moderate sensory stimuli. The contribution of these to the background of mental life is doubtless significant.

The analysis of the sensory experience and the demonstration of the dependence of its components upon such specific physiological processes as secretory, vasomotor, pilomotor and thermal change is now a matter for further study.

VISUAL MOVEMENT UNDER SIMULTANEOUS EXCITATIONS WITH INITIAL AND TERMINAL OVERLAP

BY RUTH FRANKLIN McCONNELL

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Experimental studies of visual movement have generally been based upon the successive presentation of stationary objects with a brief interval. Almost from the first attention has been directed to temporal disjunction as an important factor conditioning the perception of apparent movement.

Exner, one of the first to remark upon its importance, found that a temporal interval necessary to the perception of movement was less than that necessary to perceived succession.[1] Attempts were subsequently made to determine the exact temporal conditions under which optimal movement might be perceived, as well as to discover those conditions which resulted in the perception of the objects as simultaneous and as successive. Fischer[2] professed to prove that there was an optimal time for the perception of movement; but it remained for Wertheimer[3] to crystallize the work of his predecessors, bringing their facts as grist to the mill of the *Gestalt-theorie*. Wertheimer found the temporal interval to be of great importance and he ventured to state the optimal times for full movement as being near 60 sigma and the boundary times for simultaneity and succession as near 30 and 200 sigma respectively. Among those who followed Wertheimer, confirming or rejecting his results, the work of Higginson[4] stands as a direct link with the present study. In his investigations Higginson was particularly concerned with the importance of the temporal interval and with the suitability of the *Gestalt-theorie* as an explanatory hypothesis, as well as with other points concerning the description and explanation of the experience of movement. In his first four series Higginson used practically the same general conditions as Wertheimer, presenting the members successively with an interval of from 15 to 225 sigma. No correspondence between any point or region on his scale and the perception of full movement was found. Reports of full movement were, in fact, about equally distributed throughout the series and for every temporal condition they far exceeded other types of report.

[1] S. Exner, Ueber das Sehen von Bewegungen und die Theorie des zusammengesetzten Auges, *Ber. d. Wien. Akad.*, 1875, **72**, 156–189.

[2] O. Fischer, Psychologische Analyse der stroboskopischen Erscheinungen, *Phil. Stud.*, 1886, **3**, 128–156.

[3] M. Wertheimer, Ueber das Sehen von Bewegung, *Zsch. f. Psychol.*, 1912, **61**, 161–265.

[4] G. D. Higginson, The visual apprehension of movement under successive retinal excitations, *Amer. J. Psychol.*, 1926, **37**, 63–115.

An interesting fact which came from Higginson's work was the production of apparent movement with the simultaneous presence of both members of the simple stimulus object. Both members were simultaneously present for half of a total period of exposition; one or the other being suddenly added or subtracted. Two simple objects were used, the one consisting of an oblique and a horizontal line set at an angle of 45°; the other, two parallel lines. The lines were produced by the transmission of light through narrow slits in a lightless field.

"One light (l_1 or l_2) was turned on. O attended for 5 sec, and then the other light (l_2 or l_1) was added. Both lines were then simultaneously removed after 5 sec more." [5] In half of the observations the oblique line was presented first; in the other half the horizontal. The results were somewhat surprising. With object A (oblique-horizontal) but five cases of no-movement were reported, while 88 of full-movement and 7 of partial-movement completed the 100 observations; with object B there were 84 cases of full-movement and 16 of partial-movement. The movement was described as 'strikingly clear and distinct' and was apprehended with ease and assurance. This in spite of the fact that one of the main traditional conditions for apparent movement, succession, was lacking. Substantially the same results were obtained when the two members were presented simultaneously and one or the other subtracted after a period of five seconds while the remaining member continued alone in the field for five seconds more. Here 8 cases of no-movement, 32 of partial movement and 160 of full movement were reported out of the 200 observations.

The whole procedure is deliberate and the durations long, a circumstance which the experimenter regards as an explanation of the fact that the movement was much clearer than under the old conditions. Whether or not movement is similarly obtained under excitations which are *contemporaneous* and *very brief* was not brought out. That becomes a part of the present investigation.[6] We have reduced the total exposition-time and varied within a series of minute gradations the amount of initial and terminal overlapping. Thus we approximate as nearly as we can, with simultaneous presence of the members, the temporal variations which are commonly employed in the study of movement under successive stimulation.

[5] *Ibid.*, p. 77.

[6] The study was directed by Professor Bentley. For the adjustment of the exposure-apparatus and for frequent help and counsel, the writer is indebted to Dr. Higginson.

The Experiments

Our apparatus was the modified mirror tachistoscope which Higginson has used in related problems.

The three-ply wooden disk which controlled the expositions was adjusted to permit the simultaneous presentation of two objects and to provide for the presentation of one member for a variable time before, or for its continuance beyond, the other. Two radial slits, extending from a common radius for 27° and 84°, respectively, provided for the adjustable exposition of the members. On the longer sector, the distance from 27° to 84° was graduated in equal increments of 2.5° (or 7.5 sigma when the disk was rotated at the rate of 0.9 sec), forming a scale of 20 units. Thus the maximal overlap (initial or final) was 142.5 sigma. An adjustable shield, fitted to move over the graduated arc, provided for the variation of the member exposed by this sector. By a simple exchange of the objects within the Dodge box either member could be so varied, and the disk could be rotated in either direction. The direction of rotation ('normal' or 'reverse') therefore determined whether the variation was to take place initially or terminally. The disk was actuated by a constant-speed motor and a reduction-cone of sixteen grooves. The rate of 0.9 sec was kept constant and regularly checked.

Our general procedure was to present two straight lines in an oblique-horizontal position forming an angle of 45°. The object was composed of two members, the horizontal (*H*) and the oblique (*O*). These lines were produced by slits 1 mm × 25 mm cut in black opaque cardboard, lighted from behind. The members were apprehended as lines of light on a lightless field. Four series of experiments were conducted, each consisting of 200 observations (10 at each of the 20 points on our variable scale) from each of three observers.[7] The order of the variations in each series was haphazard, since we hoped to avoid both cumulative effects and observational set. The following diagram illustrates the general plan.

Exposure Times

Constant (O or H) 67.5σ

steps 20·····3, 2, 1 Variable (H or O) 1, 2, 3·····20 steps

Initial Overlap — Terminal Overlap

i. *O* was varied initially; *H* was constant
ii. *H* was varied initially; *O* was constant
iii. *O* was varied terminally; *H* was constant
iv. *H* was varied terminally; *O* was constant

[7] The observers were F. J. Faissler, L. Steffy and W. D. Turner, senior students in psychology, each pursuing a laboratory problem of his own. In the second half of the main series, McConnell replaced Faissler.

The experiment was conducted in a dark room with a small desk light for the use of the experimenter. All general illumination was excluded from *O* by a complete enclosure of black cloth. A head-rest and an adjustable chair made possible a comfortable and fixed position.

At the beginning of each observation *O* was required to read the following printed instructions.

"Fixate steadily the small lighted area in the box. Close first the one eye and then the other to make sure that you see the light with both eyes. When the lighted area disappears, continue to observe the field without change in fixation. Observe carefully whatever comes and report orally to *E*. Be sure to include in your descriptive account particular and precise statements as to the order and nature of the appearance and disappearance of the phenomenal object or objects."

At a preparatory signal the control-key was lifted, giving fixation. At 'now' the fixation light was removed and immediately the object was presented by closing the switch which lighted the radial sectors as they passed the exposure areas. After the radial slits had completely passed the light-source, giving one exposition of the members, the switch was opened and *O* reported at once. An occasional tendency of *O* to speculate upon the apparatus, the arrangement of the physical objects and the procedure, or to employ interpretation and inference in the report was discouraged by verbal comment or instruction. This tendency was wellnigh eliminated in the preliminary series of 100 or more observations required of each *O*: only an occasional reminder was necessary during the regular experiments.

The Results

Table I gives a summary of the reports of full movement (*F*) and partial movement (*P*) for each observer under each of the variable conditions. The two frequency polygons (Figs. 1 and 2) represent the sums of these reports for the three observers with *F*, *P*, and $F + P$ plotted separately.

When the results under initial overlapping are compared with those under terminal overlapping the reader will note differences both in the number of reports of movement and in their distribution upon the scale. Of 1200 reports under the first condition, 906 were of movement ($F = 473$; $P = 433$) while of an equal number under the second, only 478 were of movement ($F = 184$; $P = 294$). The curve which represents initial variation (Fig. 1) rises very rapidly from 8, total cases of movement at simultaneity, to 48 movements at 45σ (the seventh step on the scale). But the curve for terminal variation rises slowly and irregularly from 10, at simultaneity, to 45 at its highest point, 142.5σ (the twentieth, or last, step of the scale). The general and consistent upward trend of the figures suggests that the perception of

TABLE I

MAIN SERIES

Initial Variation

Exposure (in σ)	0		7.5		15		22.5		30		37.5		45		52.5		60		67.5		75		82.5		90		97.5		105		112.5		120		127.5		135		142.5	
Type Mv't	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P
Oblique																																						
Obs. F	0	1	0	1	3	1	5	2	4	2	5	2	8	2	7	2	7	2	4	5	5	3	4	6	5	5	2	6	1	7	3	5	3	7	6	4	3	6	6	4
S	0	1	3	2	2	2	2	0	2	2	1	2	5	0	4	3	6	1	5	1	3	7	5	5	3	6	4	6	4	6	4	5	2	5	6	3	5	5	4	5
T	1	1	4	1	4	2	3	4	7	2	6	3	7	3	10	0	9	1	6	4	1	7	1	9	4	6	3	7	3	6	3	7	1	9	0	10	1	9	4	6
Horizontal																																							
Obs. F	1	0	0	0	2	0	4	1	5	3	4	2	7	2	5	5	7	3	3	6	5	4	4	6	9	1	7	3	10	0	9	1	6	4	10	0	7	3	8	2
S	2	1	0	2	1	3	1	4	1	4	0	4	3	4	1	6	4	5	5	2	8	2	7	2	9	1	8	2	9	1	7	1	2	6	5	2	7	1	7	2
T	0	0	0	0	0	0	0	0	0	2	0	4	0	7	0	9	3	6	0	10	1	8	5	5	5	5	2	8	6	4	4	6	7	2	4	6	5	5	2	8
Total	4	4	7	6	12	8	15	11	19	15	16	17	30	18	27	25	36	18	23	28	23	31	26	33	35	24	26	32	33	24	30	25	21	33	31	25	28	29	31	27
Total Mv't	8		13		20		26		34		33		48		52		54		51		54		59		59		58		57		55		54		56		57		58	

Terminal Variation

Oblique																																							
Obs. M	0	2	0	2	0	1	0	3	0	2	0	2	0	1	0	2	0	5	0	3	0	4	1	6	1	2	1	4	1	5	0	4	1	2	2	6	3	4	4	5
S	0	0	2	0	2	1	2	0	2	1	2	2	2	0	1	0	3	0	1	3	0	2	2	3	0	2	3	1	3	3	2	2	2	5	5	3	5	2	6	2
T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	2	0	3	0	3	3	4	1	5	1	5	2	4	0	3	4	4	3	4
Horizontal																																							
Obs. M	0	4	0	4	1	4	0	4	1	4	1	2	1	2	0	4	0	3	2	7	0	5	0	6	2	4	1	5	2	3	1	5	1	1	1	4	0	7	0	6
S	3	1	2	0	2	0	4	1	3	1	4	3	6	3	2	2	2	2	5	1	7	2	5	0	3	0	6	0	6	0	6	1	6	1	4	1	5	2	7	2
T	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	2	0	2	1	2	0	1	0	3	0	2	0	5	0	5	2	5	2	4	0	5	2	6	1	5
Total	3	7	4	6	5	6	7	9	6	8	7	10	9	8	3	10	5	12	9	18	7	16	8	21	6	13	14	19	13	21	12	22	14	17	12	22	19	25	21	24
Total Mv't	10		10		11		16		14		17		17		13		17		27		23		29		19		33		34		34		31		34		44		45	

movement is *a function of the increase in the temporal variation of one of the lights.*

I. Types of Movement and Degrees of Overlap

In tabulating these results we have put down as *full-movement* those reports in which the observer has characterized the perception as meaning that movement had taken place

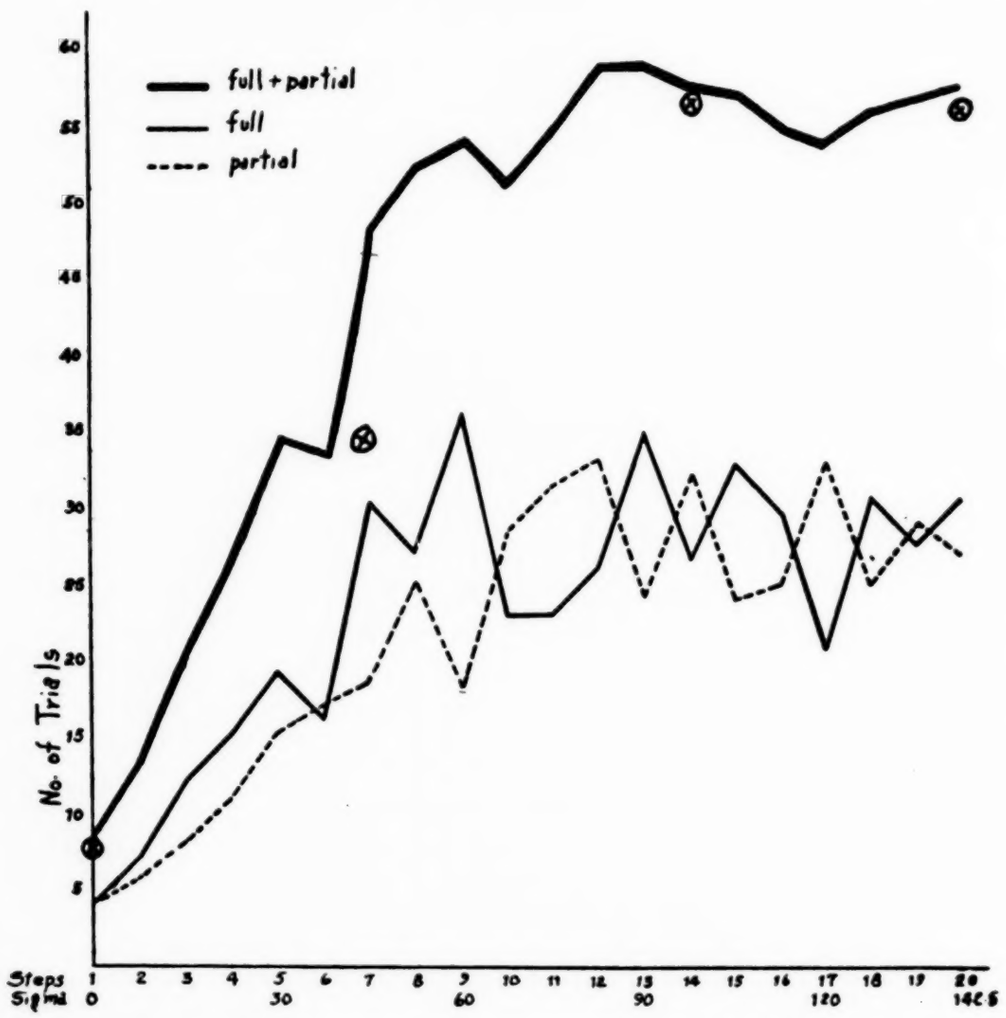


FIG. 1. The perception of movement under initial overlapping

over the whole area between limiting members, and *partial-movement* those in which the perception meant movement over only a portion of the phenomenal area. It was not considered necessary that movement be referred to a line or other object; though reports (such as the following) of movement apart from the object-line were rare (*a*).

O and *H* appeared together; but there seemed to have been movement between them. They disappeared simultaneously. There was a shutting down effect (movement in a downward direction) without its being related to either line. 9*F* [7]

O appeared followed by two simultaneous events: (1) a motion to horizontal and (2) the appearance of the horizontal line. *H* did not seem to have moved down from above. It just came. But the motion was also clear, though not related to either line. Do not know the order of disappearance. 9*T*

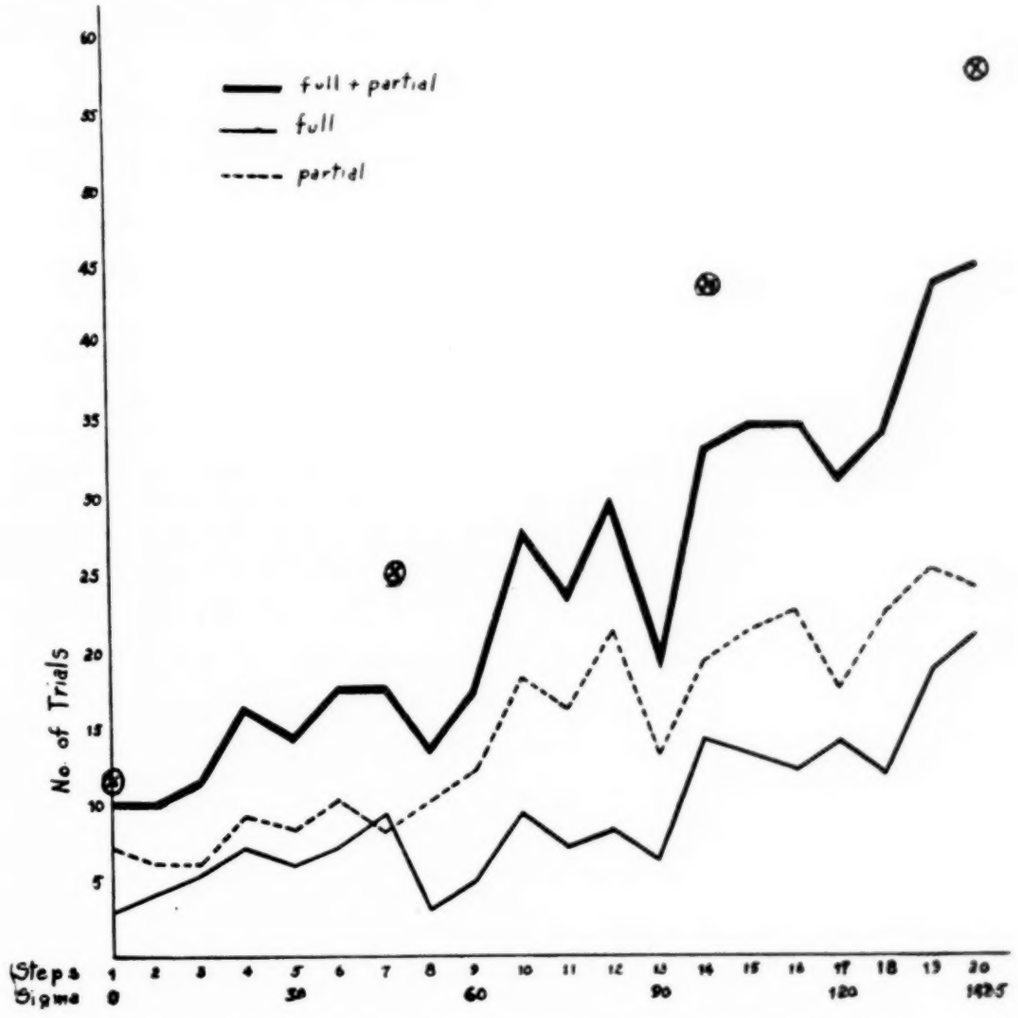


FIG. 2. The perception of movement under terminal overlapping

(*b*) Observers occasionally reported that the moving line was apprehended at successive stages during its course.

H appears followed by *O*, which is seen at two separate positions in the area between *H* and its final position; once about 1/4 of the distance, again at 3/4, and finally at the normal oblique position. Then *O* moved down over the upper 1/4 of the angle and disappeared. 10*M*

[7] The figure refers to the step on our scale; the letter to the observer. The reports which follow are given in order of the steps, from simultaneity to the maximal overlap at the 20th step.

H appeared, followed by the motion of a line from it to the oblique position. The line moved up over the lower 2/3 of the area, paused and then continued to the oblique position. Then both lines were wiped out. 15*T*

H and *O* appeared in the form of an acute angle. *H* disappeared by moving all the way up to *O*. The movement is clear and precise. Successive positions are seen as the spokes of a wheel. 18*M*

(*c*) The above reports are exceptional. By far the most usual type of report for full and partial movement is as follows:

H appeared first. The oblique line unfolded from it, the movement being visible only over the upper half of the angle; but the impression was clear that *O* had originated in *H*. 8*S*

H appeared. Then a motion upward of indefinite extent of the *O* line as it came to its position. The starting-point of the motion is not clear in the lower part of the field: it gradually grows clearer as the line nears its final oblique position. 9*T*

A line appeared in the oblique position. Then another line unfolded to the horizontal position moving over the whole distance from *O*. Did not see it move. Don't know how I knew it moved; but the perception was perfectly clear. 15*S*

O first. *H* dropped down all the way from *O* to horizontal position. As *O* disappeared it dropped down slightly; hardly more than its own width. The movement of *H* was very clear, distinct and deliberate. *O* was indefinite; almost a flicker. 16*F*

Simultaneous appearance of *O* and *H* lines in form of an acute angle. *H* line disappears first by moving up toward *O* (motion not distinct); *O* is then wiped out. 19*T*

(*d*) "Plural" movement. Under *F* and *P* we have also included reports which, for want of a better term, we shall call *Plural Movement; i.e.* two or more movements across the area between the two members. Both movements were at times referred to the same line; at other times to different lines and, again, were interpreted as taking place in the same direction or in opposed directions. Ordinarily the most conspicuous of the movements involved in these cases possessed the same characteristics of direction and reference which distinguished the majority of reports of single movement under the same combination of conditions.

The two lines appeared together. Then *O* disappeared, seeming to move down to join *H*; but *H* does not get brighter or thicker when *O* has completed the motion. The oblique then reappeared by moving back to its position. It was as if a book were slammed shut and then opened. *H* was in the field all of the time. The lines finally disappeared together. Cannot account for the impression of swift motion. There was nothing about the area between the lines to explain it, nor was *O* seen in successive positions in the course of motion. 8*F*

H first. Then *O* rose to its position moving clearly over the upper 1/5 of the area between the lines and immediately moving down. Both movements were clearest over the lower 1/3 of the angle. Counted 1–2–3. 9*S*

H appears. *O* then appears in motion over the upper 2/3 of the area to its position. Then *O* disappears in a slight motion downward simultaneously with the sudden wiping out of the *H* line. 14*T*

O first. *H* folded out over full angle, seeming to originate in *O* and drop to position. Then *O* went down to *H*, moving all the way from its original position to join horizontal. Movement was downward and full both times. 19*S*

O appeared and rose up about 1/3-inch to its final place. Immediately *H* fell down all the way to the horizontal position, and during this second motion (though I can't say just when) *O* disappeared—was apparently just wiped out. 19*F*

A combination of factors seems to determine the distribution of *F* and *P*. Our tables indicate that each individual is about as apt to perceive partial-movement (or full-movement) at one step as at another; *i.e.* there is nothing to indicate that any region on the scale is favorable to either type of report. On the other hand, it is also apparent that some observers favor full to partial and others partial to full.

Under terminal variation the total reports of *P* are about 1.6 times as numerous as those of *F*. Obs. *T* and *S*, whose reports under initial variation were about equally divided between *P* and *F*, show decided changes under the new conditions. Obs. *T* reporting *F* in only about 1/4 of the cases, and *S* reporting *P* in only about 1/3. *M*, a new observer to replace *F*, shows a decided balance in favor of *P*.

It is clear that such disparities preclude any generalizations as to the conditions which best favor one type or another. No doubt several factors combine to determine the report. For our purposes, therefore, we have found it best to consider simply *movement*, taking the sum of the full and partial movements as represented in the tables and in the graphs.

II. Initial Variation

A further analysis of the results under our various conditions indicates interesting correspondences as well as differences with respect to the direction and reference of the movement. With initial overlapping, movement was, in a large majority of cases, related to, and in the direction of, the second member to appear, where the second was the constant. Thus, with the oblique line variable, the following reports are characteristic:

(*a*) With oblique line variable in temporal overlap.

Oblique appeared followed by the motion of a line to horizontal from about half-way down leaving a gray patch. Both lines were wiped out simultaneously. I do not see the line at the half-way point or in motion. The idea of movement comes from the position and shape of the gray patch. 7*T*

O appeared, then *H*, giving the impression that *O* had opened like a book. *H* disappeared by moving upward into *O* as if the book were shutting up. Do not know what conveyed this impression. 10*F*

A line appeared in the oblique position. Then another line unfolded from it to the horizontal position moving over the whole distance from *O*; but the first line remained stationary. I don't know how I knew that it moved, but the meaning was perfectly clear. 15*S*

O appeared. *H* dropped down over the lower 1/4 of the distance between *O* and its final position. The movement was very clear and slow. It was like an opening hinge; but the line was not seen in successive positions. 17*F*

(*b*) When the horizontal member was varied, the direction of motion was reversed; but the reference was still to the second member to appear (in this case, the oblique).

H appeared in position simultaneously with the motion of a line to the oblique position over an indefinite extent. The starting point of the motion was not clear in the lower field. The motion grew clearer as the line neared its final oblique position. 9*T*

H appeared first and remained stationary. The oblique folded upward from *H* to its position and the lines disappeared simultaneously. 14*S*

H first, followed by the motion of a line to the oblique position over the upper 1/2 of the angle. The oblique then disappeared in a motion downward of indefinite extent and the horizontal was wiped out just as *O* completed the motion and disappeared. 15*T*

H first. *O* appeared in two jumps with a stop midway between the horizontal and oblique positions. *O* was not very bright; but the impression of jerky upward movement was clear. The line was seen in its intermediate position. 20*F*

H first and remained stationary. *O* was continually moving. First it appeared by moving out of *H* (upward). Then it returned almost to *H*, then moved up to oblique position and finally disappeared by merging with *H* again. 20*S*

(*c*) Special cases. As between movement down (*O* variable) and movement up (*H* variable), we note no particular qualitative or quantitative differences. It will be observed that in most of the above reports phenomenal sequence and the perception of movement coincide with objective sequence. But clear movement occasionally occurs when the observer fails to apprehend correctly the sequence and also when the movement is referred to the variable rather than to the constant.

H appeared, then *O*. Then the horizontal line disappeared, apparently rising up to *O*. The movement was not defined over a certain extent. At the completion of the movement there was a distinct flash of *O* which meant that *H* had merged with it. 6*S* (H_v)

H appeared first. *O* unfolded from it over the entire angle and back to it over the entire angle. I can find no way to describe what gives me 'movement.' 18*S* (O_v)

III. Terminal Variation

So far as the clearness and insistence of the movements are concerned, no striking differences appear between initial and terminal reports. There is, under terminal overlapping, however, a notable difference in ability to apprehend the sequence of the objects as well as the direction and reference of the movement. Though the presentation is objectively simultaneous, one line (usually the variable) is almost always apprehended as appearing before the other. In scarcely half of these terminal cases does the objective sequence correspond to the observed. Moreover, the direction and reference of the movement do not bear the same relation to the phenomenal sequence as they did under initial variation. Here, no matter what the order in which the lines are perceived, the movement is almost always upward, referred to the constant, and in the direction of the variable.

(*a*) When *O* is varied terminally and *H* is constant, we find, then, the following type of report.

O first. *H* just appeared, coming on slightly after the appearance of *O*. *H* disappeared first, moving over the lower 1/2 of the angle toward *O*. 11*M*

The two lines appeared simultaneously. *H* then folded up to the oblique. The horizontal was there in its own position only an instant. The upward motion started almost immediately upon the appearance of the lines. Movement was very fast. 12*S*

O first, followed immediately by the appearance of another line about half-way down which fell immediately to the horizontal position and then rose up to the half-way point again (to its point of origin) and then disappeared. 16*T*

Simultaneous appearance of the two lines followed by the disappearance of the horizontal in a motion up to *O*. The motion is not distinct. *O* is wiped out just after *H* joins it. 19*T*

Oblique first. The horizontal appeared in its position and immediately folded up all the way to *O*, disappearing by merging with the oblique line. 20*S*

(*b*) When *H* is varied terminally there are likewise disparities between objective and perceived sequence and peculiarities of reference and of direction. Here it is the horizontal

(the variable) which is usually apprehended as appearing first. The movement, in these cases, is upward and referred to the oblique line, *i.e.* to the disappearing member.

H first. *O* rose up from it over the whole angle and disappeared by moving down to *H* also over the whole angle. 11*S*

H and *O* appeared simultaneously in the form of an acute angle. *O* moved downward without definite limit and *H* was wiped out sometime during *O*'s motion. 15*T*

O first. *H* folded out of it to position and immediately *O* disappeared by folding back into *H*. 17*S*

H appeared simultaneously with the motion of a line from *H* to *O*. *O* was wiped out, then *H*. 20*T*

We are at a loss to account for the peculiarities of direction and reference under terminal variation. With initial variation, the member which was *added* was usually observed to move down or up, as the case might be, from the other, which was first in the field. Likewise, under terminal variation, with *O* as the variable, the member which was *temporally shorter* (*H*, the constant) was usually interpreted as moving toward the remaining member (*O*, the variable). We should expect, therefore, upon exchanging the members and varying *H*, that *O*, the constant, would appear to move down toward the variable. The persistence of the upward movement, under these conditions, is even more strange if considered in the light of those theories of eye-movement which stress the fact that the eyes move downward with greater ease and rapidity.

One thing seems clear. The perceived sequence has a greater effect in determining the direction and reference of the movement than does the objective sequence. When the two coincide, as in initial overlapping, the movement is in the predicted direction. When the perceived sequence is at variance with the objective, the direction and reference of the movement are subject to certain peculiarities, which are, however, in many cases reasonable in the light of the order in which the members are perceived. We are unable to explain the inability of our observers to apprehend at times the members as appearing simultaneously when the lines were so presented.

IV. No-Movement and Aberrant Movement

Not the least interesting of our reports are those which do not fall under *F* or *P*. (*a*) Of these a great many were of no-movement. The lines were apprehended as completely simultaneous in appearance and disappearance and were often regarded as one object—an acute angle.

O appeared and disappeared simultaneously with *H*. The relation of the two lines was that of an acute angle of about 45°. There was a pale misty light between and around the lines. 1*T*

H and *O* appeared and disappeared together. They were in the form of an acute angle of about 40°. At about the middle of the exposure, the figure as a whole moved slightly nearer to me. 4*F*

H and *O* appeared together in their usual position. There was no movement. They were just there an instant and then they were wiped out all at once. 8*S*

The two lines appeared simultaneously. There was a slight flickering along the length of the horizontal line and a vague mist in the area between the lines, but no movement. 11*M*

(*b*) Again the lines were sometimes apprehended as appearing in sequence, but with no movement.

No movement at all. The oblique might have appeared an instant before the horizontal, but I am not sure. The disappearance was simultaneous. 5*F*

H appeared slightly before *O*. *O* was dim and flickering and disappeared very soon after it came. The horizontal remained an instant longer than *O*. 12*M*

O appeared in its place. *H* just appeared, forming an acute angle of about 40°. The disappearance was simultaneous. 16*S*

H appeared first, then *O* appeared. Immediately after *O* appeared, *H* was wiped out. *O* remained for a while longer. There was a slight flash as *H* disappeared; but no movement. 17*S*

In general, the distribution of these reports of no-movement was, under both terminal and initial variation, approximately the inverse of the distribution of *F* and *P*. At the lower steps of the scale (usually below 5 for initial and below 15 for terminal variation) they were decidedly more frequent than in the upper regions. No temporal condition, however, precluded these reports.

Reports of dual movement (both lines moving) and of intramembral movement (movement within a given line) appeared without reference to any interval or group of intervals. These reports came but rarely under initial overlapping, and with greater frequency under terminal overlapping. With the latter condition, it was not infrequent for intramembral movement to accompany the perception of downward or of upward movement.

(*c*) Some examples of dual movement follow.

The lines *H* and *O* appeared simultaneously and then moved slightly away from each other, widening the angle. They remained an instant and then disappeared. 6*T*

Both lines appeared to move from the center of the angle; *O* up, *H* down. When they reached their usual positions, they immediately disappeared. The spreading apart as the lines appeared was like the opening of scissors. 8*S*

H and *O* appeared simultaneously. The angle was smaller than usual (about 30°). It widened to normal size, *O* moving slightly up and *H* moving down. Then both lines moved back to their original positions and disappeared. 10*M*

H and *O* appeared simultaneously. *O* rose up about 1/8-in. over the upper part of the field and at the same time *H* fell down over about 1/8-in. of the lower part of the field. The effect was a widening of the angle. The lines disappeared simultaneously. 15*F*

(*d*) Intramembral movement likewise was often clearly described.

H and *O* appeared simultaneously. *H* disappeared in sections, being erased from both ends while *O* was wiped out simultaneously. 5*T*

O appeared first, then *H*. Each line came with a running-along movement within itself as it found its place. *H* disappeared; then *O*. 13*M*

H and *O* appeared simultaneously. Then *O* was wiped out all at once. *H* disappeared along its own length, seeming to run down into the apex of the angle. 17*S*

O appeared first. *H* shot out of the left corner of the angle. It was a gradual revealing of the line from the left end outward to the right, as if the line were being drawn out. 17*S*

V. The Commentary

By way of commentary each observer from time to time and in his own way sought to describe factors which seemed to him explanatory of, or contributory to, his perception.

T several times observed a qualitative difference in the area between the lines which varied in shape from time to time and which, as he surmised, aided him in estimating the direction and extent of the perceived movement.

> "The motion idea comes from a patch of darker gray which trails over the area covered by the moving line." "The meaning of motion comes from a gray patch in the area between the lines." "I do not see the line in motion or in successive positions; but the idea of movement comes from the position and shape of the gray patch." (3*T* reports)

When *T* reported two movements he described the gray patches as overlapping, each one retaining its own identity and relationship to its own moving line.

The other observers occasionally speak of lighted areas between the lines, but do not give detailed descriptions of their size, positions and relation to movement as does *T*. *F* found that 'flashes' and downward sweeps of light contributed to the experience. The latter she compared to a 'spot light' sweeping upward or downward over the field.

> *H* first. Then *O* appeared, not as if it had moved up from *H*; but as if a wave or spot of light had illuminated first *H*, then *O*. It was a movement of light rather than of the line. 8*F*
>
> *O* was there first; then *H* came. It seemed as if a spot light had swung over the field revealing first the oblique, then the horizontal. It was not the usual impression of a line itself moving down. 13*F*

S found that a flash of the stationary line contributed the meaning of one line's emerging from, or joining, the other; and that a movement over the whole area had been completed.

> *H* appeared, then *O*. *H* disappeared, apparently rising up to *O*, though the movement was not defined over a certain extent. There was a distinct flash of *O* which meant that *H* had completed its movement and had joined *O*. Then all was wiped out. 6*S*

S also reported accompanying kinæsthesis. She was unable to decide whether this contributed to the experience of movement, or was the result of it.

> *O* appeared first and was very bright. A line fell out of the oblique to form the horizontal, swinging down evenly. A distinct, sub-vocal, 'one-two-three' counting accompanied this experience: one meant the appearance of *O*; two, the flash downward; and three, the appearance of *H* in its proper position. 10*S*

T and occasionally the others reported kinæsthesis about the eyes, but no other observer has commented upon vocal kinæsthesis.

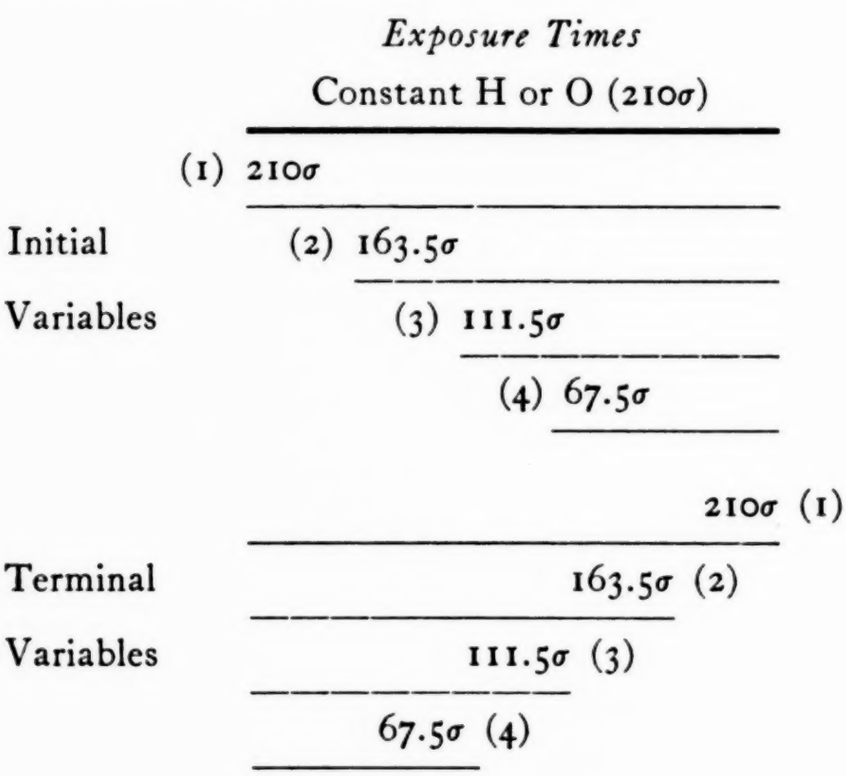
From time to time reports of an increase of brightness during the course of the observations were made by all observers. *F* and *M* remarked this most frequently. At times it meant the jumping forward of the whole figure and again it was simply an adjunct of the usual perception of movement.

> *H* and *O* appeared and disappeared together; but at about the middle of the exposure the lines suddenly brightened and the whole figure seemed to jump toward me. 4*F*
>
> *H* appeared first and was very dim. Then *O* appeared. Both lines grew brighter; then *O* swung down 1/2 of the way to the horizontal position and disappeared. *H* disappeared while *O* was moving down. 10*M*

Control Series

Going back to the quantitative analysis of our results it is apparent that, under all conditions, movement was more readily perceived the greater the temporal extension of the variable member beyond the constant. It will be remembered, however, that each increment of our scale, increasing the exposition of the variable member, also increased the total exposition. The question was therefore raised whether the increase of movement reports under the condition of increased overlapping of the variable was actually a function of that condition or due to the increase in the total time of exposition. A control experiment was accordingly devised to provide a constant *maximal* period of exposition within which one member might be varied, and also to distribute practice effects by combining both initial and terminal overlaps in a single mixed series.

An adjustment was made in the disk to allow for the presentation of either member for 210 sigma. One member was to be exposed for the full time; the other could be adjusted at any one of four steps and would remain for 210, 163.5, 111.5 or 67.5 sigma. These steps corresponded approximately, in amount of overlapping, to nos. 1, 7, 14, and 20 in our main series. The times and the overlaps conformed to the following schema.



Thus, under the new conditions, the maximal duration of the exposure was always constant, the variable falling short of it at the beginning or at the end.

Two Os were used: St, who had served (as S) throughout the experiments, and Su, an experienced subject who had observed for Higginson in related problems. 320 reports, 40 under each of our eight possible conditions (4 initial and 4 terminal overlaps), presented in a single haphazard order with respect to type of overlapping as well as to order of steps, composed the series. The member (H or O) which was to be the constant was changed at each sitting.

Table II gives a quantitative summary of the results.

TABLE II

CONTROL SERIES

	Initial Variation								Terminal Variation							
Steps	1		2		3		4		1		2		3		4	
Sigma	0		46.5		98.5		142.5		0		46.5		98.5		142.5	
Oblique	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P
Obs. St	0	0	5	2	10	0	9	1	3	2	2	3	5	2	9	1
Su	0	1	0	6	0	9	0	9	0	1	0	4	0	9	1	9
Horizontal																
Obs. St	1	3	5	0	10	0	10	0	1	0	1	2	4	0	8	1
Su	0	0	0	5	0	9	0	10	0	1	0	5	0	10	1	9
Total	1	4	10	13	20	18	19	20	4	4	3	14	9	21	19	20
Total Mvmt.	5		23		38		39		8		17		30		39	

These results are generally comparable to those obtained in the previous series for like overlaps. As a means of illustrating the similarity, we have multiplied (see Table III) the new data (consisting of 20 observations at each step from each obs.) by 3/2 to make it numerically equivalent to the old, which had consisted of 20 observations each from 3 obs.

TABLE III

COMPARISON OF MAIN AND CONTROL SERIES

Initial Variation

	Overlap (in σ)	No. Mvmt. Rep'ts	Overlap (in σ)	No. Mvmt. Rep'ts	Overlap (in σ)	No. Mvmt. Rep'ts	Overlap (in σ)	No. Mvmt. Rep'ts
Main Ser.	0	8	45	48	97.5	58	142.5	58
Control Ser.	0	7.5	46.5	34.5	98.5	57	142.5	57

Terminal Variation

Main Ser.	0	10	45	17	97.5	33	142.5	45
Control Ser.	0	12	46.5	25.5	98.5	45	142.5	58.5

The comparison clearly shows a surprisingly close numerical correspondence between the number of movement-reports in the two series, overlap for overlap. It also confirms our previous conclusions; (1) that the number of movement-perceptions increases with the increase of the initial or final disjunction in time and (2) that initial overlaps has a quicker and more compulsory effect upon phenomenal movement than has terminal overlap. At approximately 100σ (97.5 and 98.5) of *initial* delay in the variable member, approximately 100 per cent. of movements (58 and 57 out of a possible 60) occur; while at the same amount of *terminal* shortening of the variable, only about 65 per cent. (33 and 45 out of a possible 60) occur.

The points on our scale of temporal disjunction for the Control Series (steps 1, 7, 14 and 20) have been indicated in Figs. 1 and 2 by circled crosses ⊗. It looks as if a simple interpolation for the intermediate steps would not go far wrong. The general similarity from the main and control series is especially striking because in the latter the observers proceeded wholly without knowledge, *i.e.*, they were ignorant as to whether a given pair of exposures was exactly simultaneous or, if temporally disjoined, whether at the beginning or at the ending.

While one obs. (as M or T) may be inclined toward *partial* movement and another (as S) toward *full* movement the proportion does not generally appear to run with the amount of overlap. It is the *sum of all movements* which is significant. We might speculate upon a specific difference in cortical chemistry; but we should probably do better to look to differences in such general matters as 'self' and 'occasional' instruction to explain the relative proportional differences between partial and full.

Emphasis has been laid by some writers upon the time elapsing between the *initiation* of stimuli preceding and following an interval; but since we have no intervals in our experiments such a dependence cannot sensibly be sought or affirmed. The plain fact, drawn from our terminal overlaps, that phenomenal movement is regularly produced under a

single initiation and with non-synchronized endings would seem to discredit any general proposal which exaggerates the importance of initiation. We do supply evidence that the increment of *initial* overlap more quickly and certainly gives rise to phenomenal movement than the increment of *terminal* overlap does; but upon the significance of this quantitative difference we are not ready to conjecture.

Again the absolute duration of the stimulus seems, among these brief times, to be without great significance. Small increments of time added at the beginning or end of a fixed duration of 67.5σ (Main Series) have about the same efficacy for phenomenal movement as like temporal disjunctions in members near 210σ (Control Series). Only in the terminal overlapping (compare Fig. 2) do the longer absolute times seem to favor the apprehension of movement; for at all four steps in the Control Series the totals for movement (marked by ⊗) fall above the corresponding totals for the briefer times of the earlier experiments.

Summary and Conclusions

We have put the new conditions for apparent visual movement (simultaneous presentation of two members without interval) to the test of a brief exposure with varying amounts of initial or terminal overlapping. Our results indicate that, under these temporally restricted and varied conditions, the movement is still readily and clearly perceived. Moreover, the frequency of phenomenal movement under simultaneous excitation bears a direct relation to the *amount* of the overlapping of one of the members of the stimulus object.

In both our main and control series initial overlapping appears to be much more favorable to the perception of movement than terminal overlapping; a delay of about 100σ at initiation producing movement in practically every case, while practically 140σ was required between the two endings (see Figs. 1 and 2) to produce the same result.

Types of movement which commonly appear under the usual conditions of successive presentation with interval are to be found among our results. Full movement and partial

movement are distributed impartially (with respect to our graduated scale) and may not, therefore, be considered as functions of the temporal conditions of the experiment. Full or partial movements within a single exposition are frequently 'plural,' *i.e.* two or more such movements may occur successively over the area between the members.

The *order and nature* of the phenomenal members, as apprehended by the observer, have as great a bearing upon the direction and reference of the movement as has the stimulus arrangement. Under initial overlapping, the Os usually apprehend movement as in the direction of the delayed member; but under terminal variation the Os often failed to apprehend the members as of simultaneous onset. In these cases, movement was frequently referred to the member which phenomenologically came last. Often a second motion was also reported, this being related to the disappearing member.

Dual and intramembral movements came most often under terminal variation. No point or region of the scale was favorable to such reports.

Commentary by our observers frequently included references to qualitative differences in the visual field which were from time to time seized upon by them to 'explain' the experience of movement. These qualitative differences varied widely among the different observers as well as within the reports of a given individual. Moreover, clear and insistent movement frequently appeared without such comment, which has, as we believe, little or no inspective value. We are not justified, therefore, in labeling this material as a 'process' underlying the experience of movement. Nor is it safe to say that the experience is so much as partially conditioned by such incidents as 'gray patch,' 'radiation of light,' 'throat kinæsthesis,' 'counting,' *etc.*, which may precede, accompany, or even follow the phenomenal movement itself.

A TEST AND ANALYSIS OF 'SET'

BY RALPH GUNDLACH, DONALD A. ROTHSCHILD AND PAUL THOMAS YOUNG [1]

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Introduction

The word 'set' has several meanings.[2] In the first place, it suggests something which is firmly established, as one's prejudices, fixed beliefs and habits. It is a fundamental biological principle that the nervous system retains its organization; that it becomes more or less permanently *set*. In the second place, the word 'set' suggests a bodily posture which an organism temporarily assumes. Thus the runner toeing the line and awaiting the gun is *set*. The cat crouching upon the floor prepared to spring upon a mouse is *set*. In these cases there is a temporary preparation for action which involves observable changes in the adjustment of muscles. In the third place, the word 'set' suggests a temporary preparation which is not directly dependent upon changes in muscular tonus. For example, after several hours of study I am *set* for my lecture. The pianist is *set* to play one of Beethoven's sonatas. Such neural preparation need not reveal itself in any particular bodily attitude. In the fourth place, the word suggests a temporary preparation for immediate action as determined by instruction. Thus in a reaction experiment the subject may be *set* to react with the right hand when a cross appears and to react with the left hand when a circle appears. As a further example, consider

[1] Rothschild assisted with the work of Part I, testing in the schools. Gundlach administered the tests described in Part II, and assisted in the experiments of Part III. For the rest of the experimental work, the supervision of the study as a whole, and the preparation of the present report, the senior author is responsible.

[2] In a recent paper diverse examples of set were listed to point out the psychological importance of certain phenomena. The present experimental approach was noted as a possibility (477). P. T. Young, The phenomena of organic set, *Psychol. Rev.*, 1925, **32**, 472–478. See also the same author's The phenomenological point of view, *Psychol. Rev.*, 1924, **31**, 295.

the test of three commissions in Year V of the Stanford-Binet scale.[3] The child is instructed as follows: ". . . Here's a key. I want you to put it on that chair over there; then I want you to shut (or open) that door, and then bring me the box which you see over there . . . ." The instruction temporarily prepares the child for action. It temporarily *sets* him, and the set vanishes when the instruction has been carried out.

The present study aims to throw light upon set in the fourth sense of the word. The experiments have two aims: (1) To analyze the process of becoming temporarily set or adjusted for action; (2) To develop a test for the capacity to become set.

Preliminary Experiments

Our first attempt was with a series of instructions of graded complexity.

The apparatus consisted of eight wooden bars (about 3 cm x 8 cm) arranged in a straight line upon a vertical board. The bars were pivoted at the top so that they could swing back and forth like gates. They could be so locked from the back side that the subject could not determine without trial whether a particular gate was locked or open. Each gate was marked by a three-letter word; BUG WAX LID KEY RIM LOG MAT TOP. A series of instructions of graded complexity was prepared. A sample instruction is: "Go to the gate WAX and if the gate is open, go through to MAT. If WAX is closed, go through BUG (which in this case will be open) to LID. If you find that MAT is closed, go to LID, but if MAT is open, go through this gate to TOP." The subject received the instruction verbally and then traced his course with a stylus.

Instructions of this type proved to be generally too complex for our subjects. It was thought best to simplify matters by eliminating contingencies. Consequently the eight words were used to designate places and not gates. The general instruction then read as follows; "On the board before you are eight places arranged in a vertical column. Become familiar with their names [half a minute was allowed for this]. I am going to ask you to go first to one place and then to another and so on. For example, if I should say 'go in order to WAX LOG TOP,' go in this way [demonstration of pointing in order to the places named]. The purpose of this experiment is to determine how complex an instruction you can carry out. I shall begin with simple instructions and then give you more complex ones."

The test consisted of three trials each with the following number of syllables: 3 4 5 6 7 8 9. The test was repeated with three-letter nonsense syllables substituted for words. Ten men and five women served as subjects. A summary of the results for the group as a whole is given below:

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[3] L. M. Terman, *The measurement of intelligence*, 1916, 172–173.

Number of places in series	3	4	5	6	7	8	9
Correctly indicated (45 trials)							
A Three-letter words	45	42	35	19	10	1	0
B Nonsense syllables	45	33	24	9	3	2	0

In view of the fact that three-letter words give significantly higher results than three-letter nonsense syllables it was decided to eliminate language so far as possible and to give the instruction by gesture. The forms of the Goddard form-board were drawn upon a white card which was placed at arms-length before the subject. The experimenter gave the general instruction 'do as I do' and then pointed (let us say) to four forms. If the subject reproduced the given sequence of movements accurately, the test was passed.[4]

In the final form our apparatus consisted of a series of ten small electric lamps arranged about the circumference of a circle and flashed one after another. The number of lights and their positions varied from test to test. The task of the subject was to observe the flashing of the lights and then to point to the positions where the lights appeared in the original order. The use of electric lamps eliminated the experimenter's pointing and also made possible the precise control of time relations during the presentation of a task.

PART I

Age as a Condition of Set

The work described in the following report was done, 1923–25, in the grammar and high schools of Urbana, Illinois.[5] There were 822 subjects ranging in age from 6 to 19 and a small group of adults. The aim of the study was to determine whether the capacity to become temporarily set varies with age, and, if so, to discover what the relation is.

Apparatus and Procedure. The apparatus consisted of a square neutral gray board, 18 x 18 inches, held by clamps and standards in a vertical position (see Figure I). Through this board were drilled in the form of a circle ten half-inch holes. The holes were equally spaced about the circum-

[4] Pointing to positions by the subject is so similar to the Knox cube test that reference to it should be made at this point. In this test four small cubes (about two inches apart) are placed before the subject and the instruction is given; "Watch carefully, and then do as I do." The experimenter then taps the cubes with a fifth at the rate of about one tap per second. The number of cubes which the experimenter touches varies from four to six and the sequence varies from test to test. The separate tests are arranged in order of difficulty. The Knox cube test demands that the subject follow with his eyes a series of movements and later reproduce them accurately. H. A. Knox, *J. Amer. Med. Assoc.*, 1914, **62**, 741–747; R. Pintner, The standardization of the Knox cube test, *Psychol. Rev.*, 1915, **22**, 377–401.

[5] The Leal grammar school (1st–6th grade); Thornburn grammar school (7th–8th grade); Urbana High School; University High School.

The ages given in the report refer to the nearest birthday. For example, age 7 includes all children from 6.6½ to 7.7½ years.

ference, the angular distance between each two being 36°. Behind each hole on a second board was a 2 c.p. electric lamp. The lamps were electrically connected to a keyboard so that

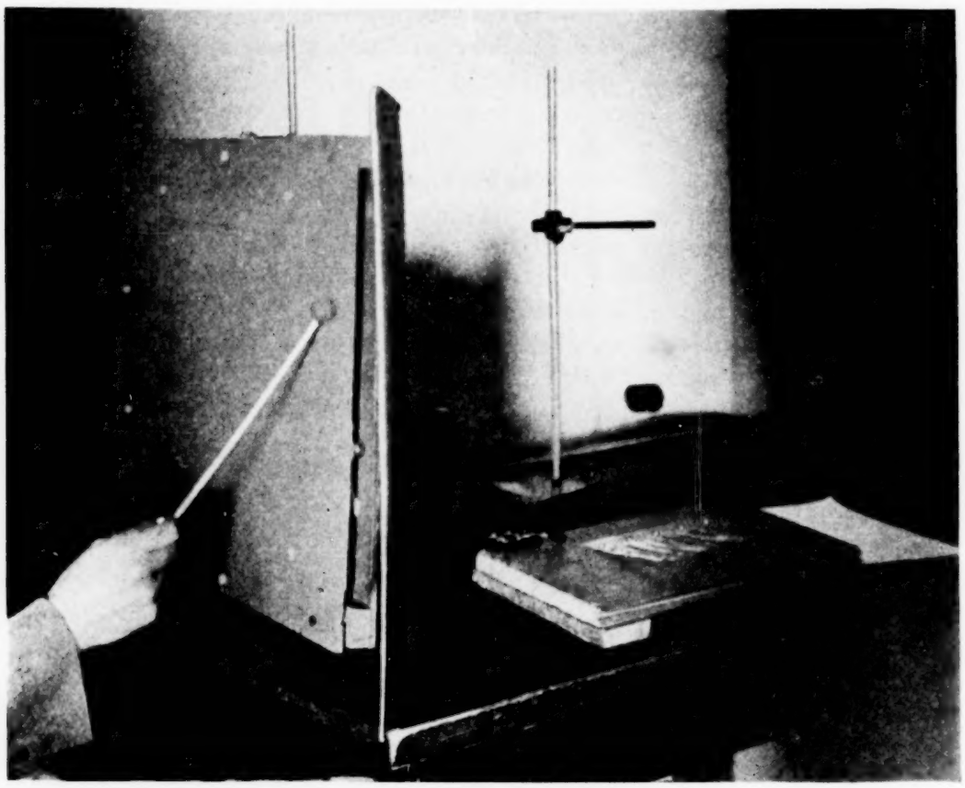
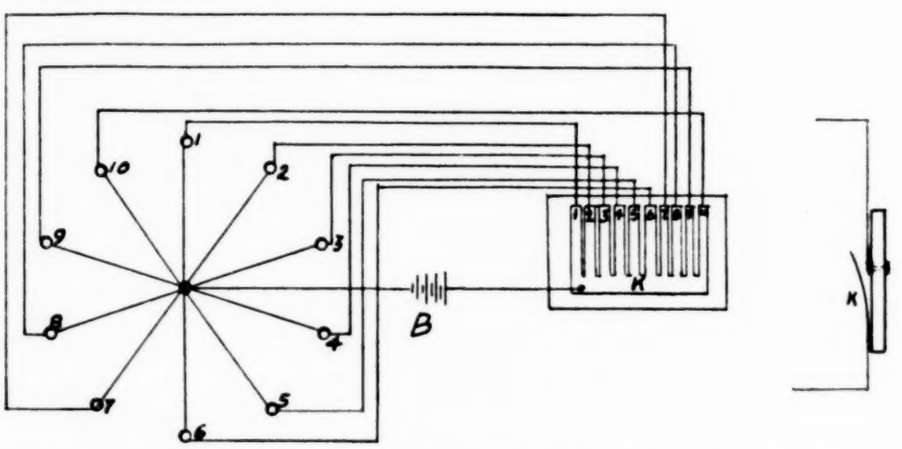


FIG. 1.

the experimenter could control the order and position of the lamps lighted. The electrical connections are shown in the following diagram.



B, battery; *K*, key-board (seen also in cross-section) for controlling lamps. The key-board was made by cutting out ten fingers from a single plate of copper. The fingers were so bent that a light pressure upon any one made electrical contact.

The lamp-board was placed upon a table in front of the subject who remained standing throughout the test. The electrical parts of the apparatus were concealed from the subject's view by means of a screen. The instruction was given orally and covered the following points:

1. On the frame in front of you are a number of lights which are going to be flashed one after the other [demonstration].

2. Note carefully the *order* and *position* of the lights as they appear.

3. After the lights have been flashed point *in order* to the places where the lights appeared.

4. There will be four trials with two lights, four trials with three lights, four trials with four lights, etc. The number of lights is going to be increased until you are not able to follow.

5. Attend carefully and do as well as possible, but do not worry if you miss.

A pointer was used in order that the subject might touch the position of the light unambiguously and with clear visibility to the experimenter. In some cases a child would attempt to start pointing before the last light had vanished. It was necessary to prevent this.

The experimenter controlled the rate of successive flashes by means of a silent pendulum which was not visible to the subject. The duration of each light was approximately 3/4 sec (not over 3/4 and never less than 1/2) and there was no interval between successive flashes in a given presentation.

The Tests. It will be convenient to designate a test by the number of lights flashed. Hence whenever we speak of Test 2 two lights were flashed; whenever we speak of Test 3 three lights were flashed, etc. Since there were four trials with each test we shall designate these in the order used as *A*, *B*, *C*, *D*. Thus Test 2*C* is the third (or *C*) test in the two light series; Test 6*A* is the first (or *A*) test in the six light series.

We show below the record blank used in the test.[6] The numbers on the blank refer to the lights which were numbered (see diagram) for the convenience of the experimenters. The individual tests are separated by double lines. Thus, in the first row are the four tests with two lights; in the second row are the four tests with three lights, etc. The lights were lighted in the order shown on the blank, and the separate tests were given in this order. The lights actually pointed to by the subject were recorded by number in the spaces provided. This was done that errors might be studied.

The tests were given in order of complexity. The subject first attempted Test 2 and if he passed any one of the four parts, he was then given an opportunity to attempt Test 3. If he passed any one of the parts of Test 3, he was then given an opportunity

[6] The word 'score' (blank) refers to an abandoned plan for computing individual test scores. The phrase 'race or color' marks the fact that a few black- and yellow-skinned children were tested; but their data have been disregarded and the present report is limited to white-skinned children.

Date..... Score.....

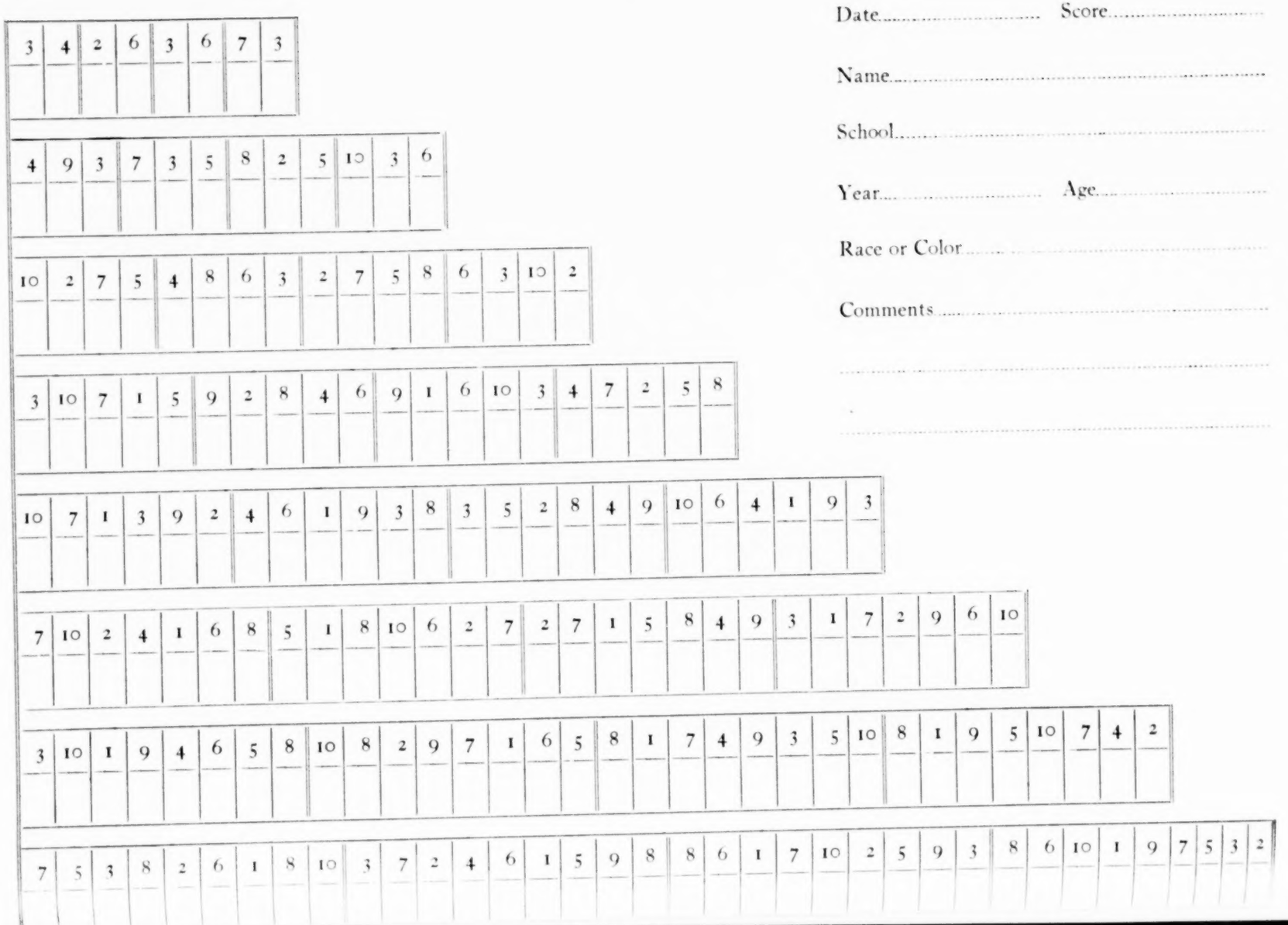
Name.....

School.....

Year..... Age.....

Race or Color.....

Comments.....



to attempt Test 4, etc. This method led to a selection of subjects with the more complex tests as follows:

Test number	2	3	4	5	6	7	8	9
Number attempting	822	822	814	759	516	180	23	0

One girl, age 9.11, clearly abnormal, was unable to point to a single light, and her case has been discarded. [7]

Data. Each individual attempt was scored 'right' or 'wrong' and no partial credit was given. The number of subjects attempting each test and the number passing each

TABLE I

Age	No. Att'pting	Number Passing							
		Test II				Test III			
		A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
6	37	37	37	35	32	17	24	21	21
7	64	63	64	61	60	46	47	46	42
8	54	54	54	54	49	43	37	43	41
9	62	62	62	62	61	52	51	55	49
10	58	58	58	58	54	50	50	48	47
11	60	60	60	60	59	51	53	56	52
12	49	49	49	49	48	46	45	45	44
13	58	58	58	58	57	54	56	54	55
14	60	60	60	60	60	58	58	58	58
15	82	82	82	82	80	81	81	81	78
16	76	76	76	76	76	75	75	75	74
17	72	72	72	72	72	71	71	70	71
18	39	39	39	39	39	39	38	39	38
19	21	21	21	21	21	20	21	21	21
20–27	30	30	30	30	30	30	28	28	30
Totals	822	821	822	817	798	733	735	740	721

TABLE II

TEST IV

Age	No. Att'pting	Number Passing			
		A	*B*	*C*	*D*
6	34	9	6	6	9
7	61	29	23	11	14
8	54	29	25	24	13
9	61	43	37	28	26
10	57	43	26	28	26
11	60	47	36	30	34
12	49	44	28	26	26
13	58	52	32	36	34
14	60	59	47	52	44
15	82	78	66	67	58
16	76	74	57	64	53
17	72	71	52	60	57
18	39	38	32	29	27
19	21	19	13	15	11
20–27	30	28	21	22	25
Totals	814	663	501	498	457

[7] Comments on her record sheet are as follows: she does not grasp the idea; can not even point to a single light; has trouble with equilibration; she sticks out her tongue and talks poorly; the teacher and mother recognize the case as abnormal.

part are given in Tables I to V. Test 8 has been omitted on account of the small number of subjects and Test 9 was not used.

TABLE III

TEST V

Age	No. Att'pting	Number Passing			
		A	*B*	*C*	*D*
6	23	1	0	1	0
7	44	4	0	5	2
8	40	3	3	12	1
9	56	5	12	16	6
10	54	8	6	11	4
11	59	6	12	20	8
12	47	9	9	23	7
13	58	21	14	27	9
14	60	30	28	39	23
15	81	53	38	52	29
16	76	49	35	50	34
17	72	41	29	51	27
18	38	26	19	31	13
19	21	11	9	12	9
20–27	30	16	12	17	9
Totals	759	283	226	367	181

TABLE IV

TEST VI

Age	No. Att'pting	Number Passing			
		A	*B*	*C*	*D*
6	1	0	0	0	0
7	12	0	0	0	0
8	15	0	0	0	0
9	29	0	0	0	0
10	21	0	0	0	1
11	30	2	3	1	0
12	28	0	2	2	0
13	43	2	3	2	5
14	52	7	9	6	6
15	72	13	12	10	15
16	68	20	17	14	15
17	66	16	16	9	9
18	35	7	6	8	6
19	20	3	4	1	5
20–27	24	5	6	4	5
Totals	516	75	78	57	67

The raw data have been converted into percentages and plotted in the form of curves (Figs. II to V). The curves show at a glance that for all ages there is an increase in efficiency accompanying growth up to the age of 14–16 years. Tests 3 and 6 indicate age 16 as the limit of growth; Tests 4 and 5 indicate age 14 or above as the limit. After age 16 the curves show no definite trend with increase in age.

TABLE V

TEST VII

Age	No. Att'pting	Number Passing *A*	*B*	*C*	*D*
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	1	0	0	0	0
11	4	0	0	0	0
12	3	0	0	0	0
13	11	0	0	0	0
14	22	1	0	1	0
15	30	0	0	1	1
16	39	0	3	0	4
17	33	2	0	1	2
18	18	0	0	2	2
19	6	0	0	0	0
20–27	13	1	2	2	0
Totals	180	4	5	7	9

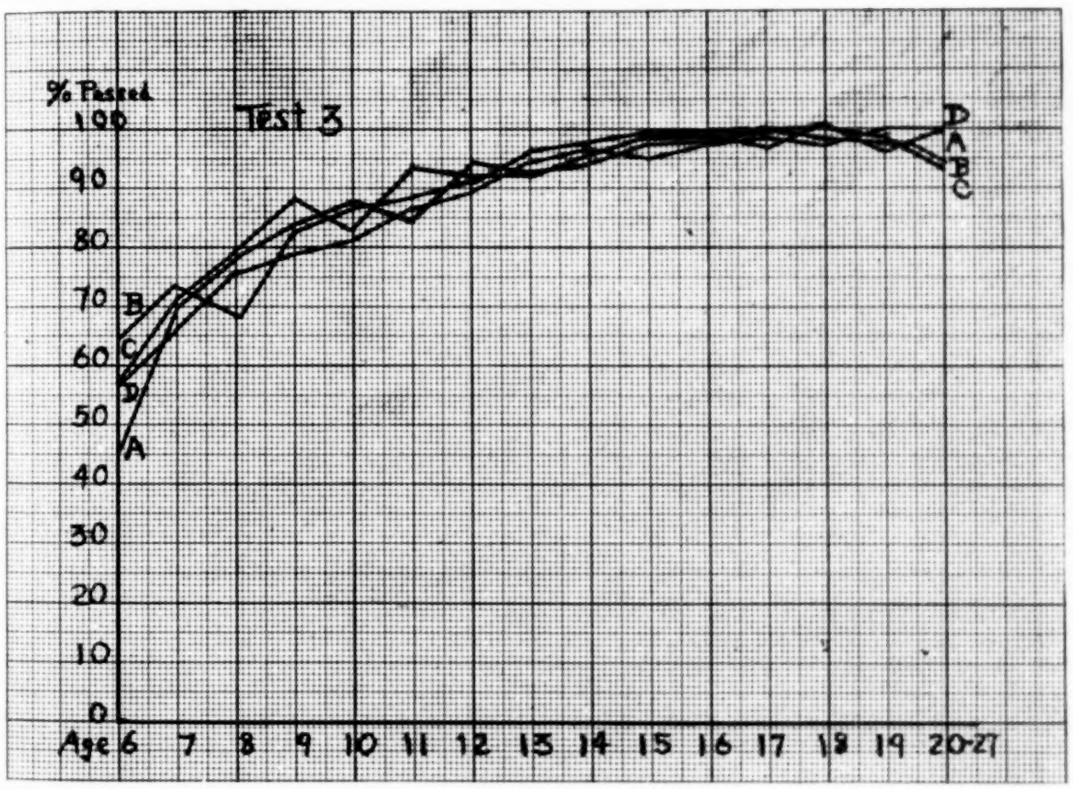


FIG. 2.

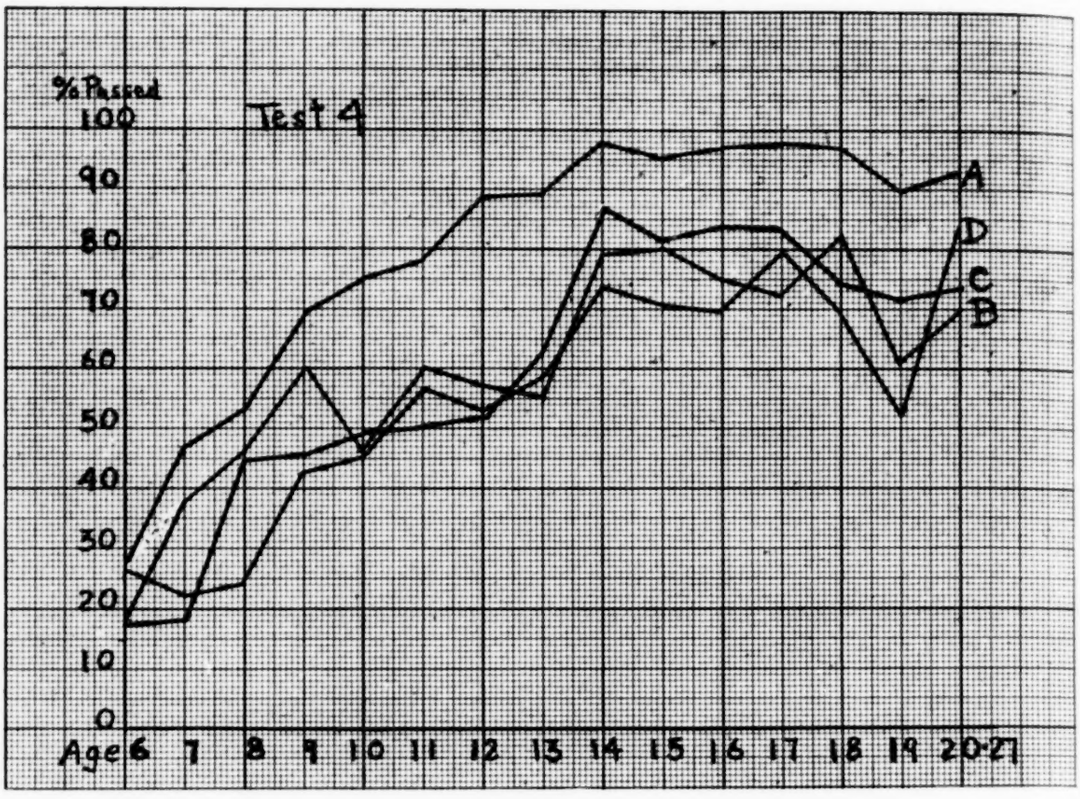

% Passed
Test 4
100
90
80
70
60
50
40
30
20
10
0
Age 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20-21
A
D
C
B

FIG. 3.

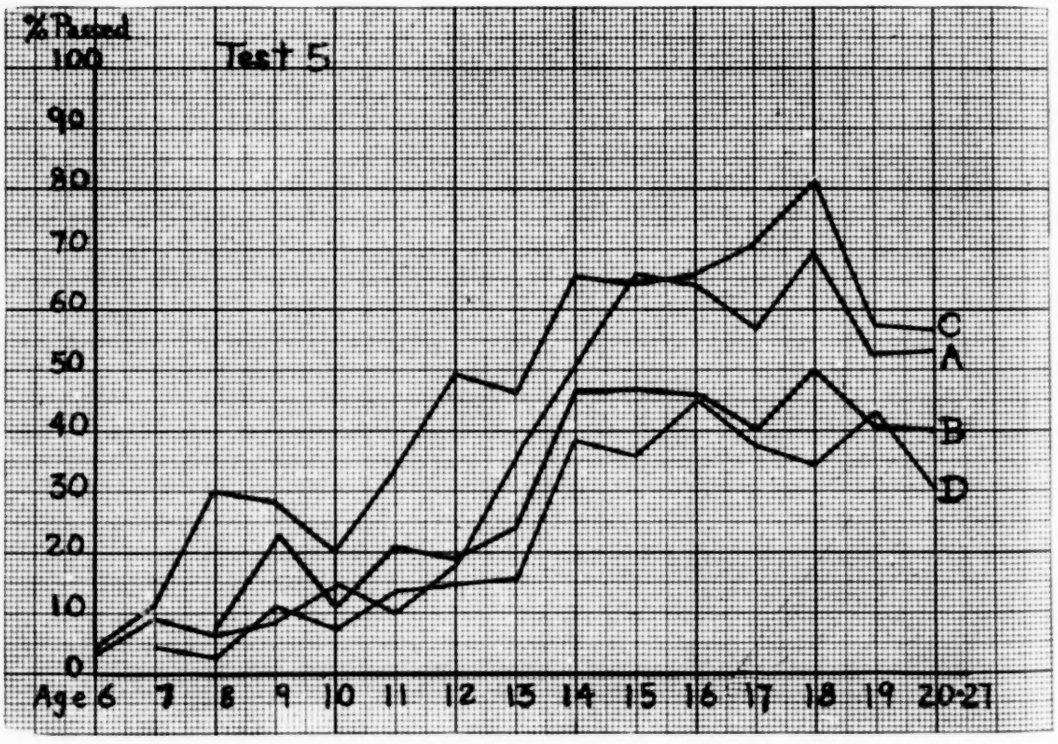

% Passed
Test 5
100
90
80
70
60
50
40
30
20
10
0
Age 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20-21
C
A
B
D

FIG. 4.

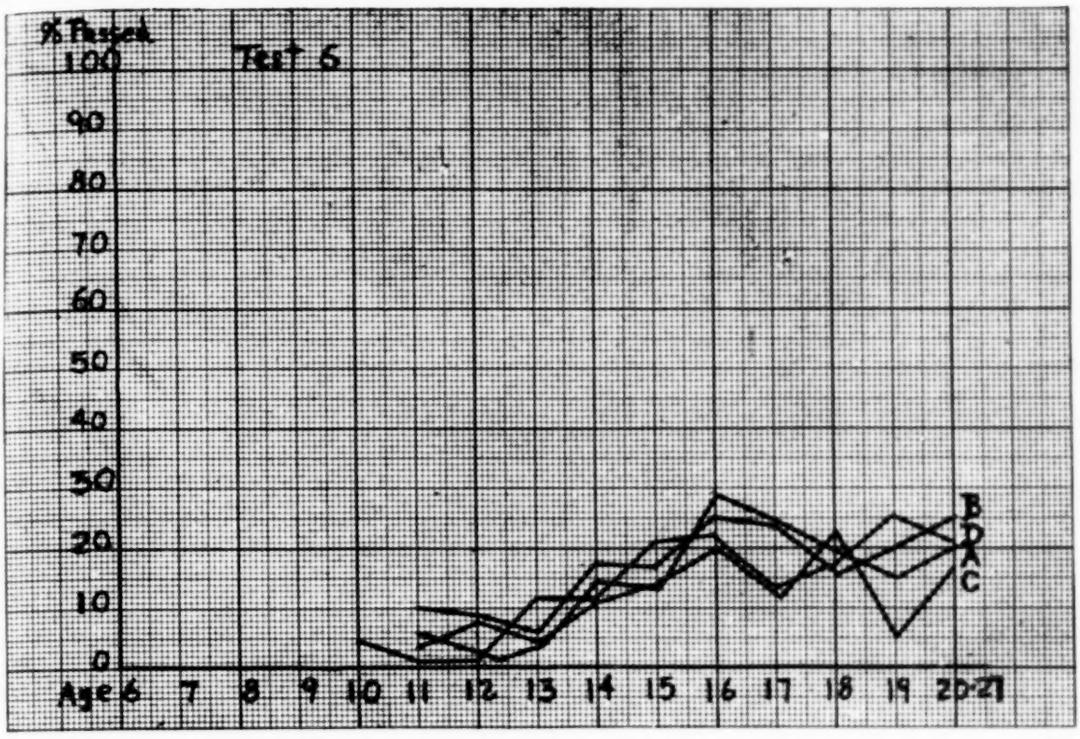


FIG. 5.

Test 2 has not been plotted since it was passed by practically 100 per cent. of those attempting it. Test 2*B* was passed by 100 per cent.; 2*A* was failed by one subject (age 7); 2*C* shows five failures (all in ages 6 and 7). Test 2*D*, however, shows a total of 24 errors which occur with greatest frequency in the earlier years and this raises the question: Why should 2*D* have significantly more errors than 2*A*, 2*B*, 2*C*?

An examination of the errors shows that 20 out of 24 are reversals of order of the two lights and that, in the remaining 4, the position of a light was missed by one place. Why should the order be reversed on 2*D* and not on the other parts of Test 2? In 2*A*, 2*B*, 2*C* the first light is spatially above the second and eye-movements as well as arm movements in pointing were made in the downward direction, whereas in 2*D* the movements of eye and arm were in the reverse direction. It is suggested, therefore, that habituation to downward movements in the first three parts predisposed the subjects to downward movements in the last part (2*D*) and thus gave rise to errors of order. It is suggested further that the less alert subjects failed to grasp the importance of having the *order* correct, or else they neglected the instructions.

If the curves for Test 3 be compared with those for Tests 4 and 5, the impression will be gained that the four parts of 3 are more similar to each other than the four parts of 4 and 5. In other words, the parts of Test 3 take approximately the same course and, further, they arise with rather remarkable smoothness; whereas the parts of Tests 4 and 5 follow quite different courses and are relatively more variable (excepting 4*A*).

The curves for Test 6 resemble 3 when compared with 4 and 5.

The variability among the parts of a test is shown in Table VI, giving the number

TABLE VI

PERFORMANCE OF ADULTS (AGES 16–27 INCL.)

Test No.	No. Att'pting	No. Passing				Per cent. Passing			
		A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
2.....	238	238	238	238	238	100	100	100	100
3.....	238	235	233	233	234	98.7	97.8	97.8	98.3
4.....	238	230	175	190	173	96.6	73.5	79.8	72.6
5.....	237	143	104	161	92	60.3	43.8	67.9	38.8
6.....	213	51	49	36	40	23.9	23.0	16.9	18.7
7.....	109	3	5	5	8	2.7	4.5	4.5	7.3
8.....	18	0	0	0	0	0	0	0	0

of adults [8] attempting each test and the number and per cent. passing each part. It will be seen that Test 2 is passed by 100 per cent. of those attempting it whereas Test 8 is passed by 0 per cent. Midway between these two extremes is Test 5 with percentages ranging from 38 per cent. to 67 per cent. Test 5 has the greatest range of variability and as we pass from 5 towards the extremely simple Test 2, or towards the extremely complex Test 8, *i.e.* as the percentages approach 100 per cent. and 0 per cent., respectively, the variability among the parts of a test becomes less.

Table VI also shows that the addition of a single light to a test series means passing to a higher level of difficulty. Every part of Test 4 is more difficult than any part of 3; every part of 5 is more difficult than any part of 4, etc. That the *pattern* of lights is also a factor underlying difficulty is shown most clearly in Test 4.

Test 4*A* is strikingly different from 4*B*, 4*C*, 4*D*. At age 6 Tests 4*A* and 4*D* are of the same difficulty. At all other ages 4*A* is very much easier than 4*B*, 4*C*, 4*D*. With adults (Table VI) the difficulty of 4*A* resembles that of 3 while the other parts of 4 are uniformily and significantly more difficult. How can we account for this difference?

Although every combination of lights was selected by chance, it happens in the case of 4*A* that the four lights make a symmetrical figure: they are the corners of a square given in an order which would make the letter Z. All other figures in the test are irregular. The subjects themselves commented that the lights in 4*A* make a square, a Z, etc. Thus, by accident, the data illustrate the principle that *pattern* is a factor underlying difficulty. [9]

---

[8] An adult is here defined as any person who is 16 years or above. The definition follows from the discovery that beyond 16 years our data show no significant variation with age.

[9] The importance of pattern and sequence of lights is fairly obvious. Eight or ten lights in a row and in a 1, 2, 3 ··· order would be indicated correctly, as I think, by most normal adults.

In the Knox cube test (see footnote 4) five degrees of difficulty are mentioned:

(*a*) 1 2 3 4
(*b*) 1 2 3 4 3
(*c*) 1 2 3 4 2
(*d*) 1 3 2 4
(*e*) 1 3 4 2 3 1

It will be seen that part (*d*), in which four cubes are touched, is considered more difficult than parts (*b*) and (*c*) with five cubes. Here the sequence is the important factor underlying the degree of difficulty.

Sex Differences. In order to discover whether there is a difference between the performance of boys and girls Tests 3 and 4 were selected for study. These tests were passed by approximately equal numbers of boys and girls. With Test 3 there is an indication that girls are slightly superior to boys between the ages of 9 and 14, but the difference is so small that it may be a fortuitous variation. With Test 4 the graphs for boys and girls are variable and they overlap. The data for 4 reveal no significant sex difference.

Conclusion. The capacity to become temporarily set increases with age from 6 to 14, or 16, years and appears not to vary after these ages.

The data reveal no significant sex differences, although there is a hint that girls may be superior to boys between the ages 9 and 14.

Efficiency in the present test varies with the number of lights presented and with the pattern which they make.

Tests with five lights show the greatest variability of performance with adults, and variability appears less as the number of lights is increased to eight and decreased to two.[10]

PART II

The Effects of Practice upon Set

During the winter months (Oct. to Feb.) of 1925–26, six-year-old children in the Colonel Wolfe School of Champaign, Illinois, were practiced on three- and four-light patterns. Patterns with three and four lights were chosen since the two-light series are too simple for six-year-old children and since, on the other hand, five-light series are practically impossible for them (see Fig. V). The patterns used were determined by chance in a manner that precluded the possibility of

[10] Under present conditions the following tests would be best for studying individual variations:

For ages below 6, tests 2 3 4
For ages 6 7 8, tests 3 4 5
For ages 9 to 13, tests 3 4 5 6
For ages above 14, tests 4 5 6 7
For superior adults, tests 5 6 7 8

It should be remembered that our method was selective and that our data cannot be regarded as normal unselected data. For the entire group, Tests 2, 3, and possibly 4, can be considered as normal. For adults (Table VI), Tests 2, 3, 4, 5, and possibly (?) 6, may be taken as normal. Had all the subjects attempted all the tests, the curves, if anything, would be lower than at present.

duplication of material.[11] No pattern appeared twice in the practice period.

Eleven children practiced two times a week for twenty-five practice periods. The work was broken by the Christmas holidays. Each subject had twenty trials per practice period, ten with three-light and ten with four-light patterns in alternation, thus: 3 4 3 4 3 4 ··· for twenty trials per series.

The apparatus and procedure were the same as described in Part I. After one or two periods of practice the routine was to ask the child if he remembered the directions and then to try him on a preliminary series of three lights. Even this became unnecessary, and after a word of greeting and the signal 'ready' the series was presented without comment.[12]

Data. The data presented in Tables VII and VIII show the raw scores made by the subjects on successive days of the

[11] The practice material for three lights, *e.g.*, was determined as follows. All possible combinations of three digits were written down on slips of paper. The slips were then shuffled, arranged in a random order and the combinations typed in columns. Now for every combination of three digits there are six permutations or orders. The six possibilities were numbered schematically and a random order of them was attached to the list of combinations. The permutation number which by chance fell to a particular combination determined the actual order of lights in any given case. Some of the combinations of three and of four lights had to be used in two permutations. So in going over the list a second time, the next higher permutation number was used, 1 becoming 2 and 6 becoming 1.

The method determines (1) that the same light will never appear twice in any particular presentation to the subject, (2) that no two presentations are the same, and (3) that the orders and patterns throughout are matters of chance.

The same general method was used in determining the four-light patterns.

Light patterns would be useful in learning and other experiments since the material is uniform, of indefinite variety, and since its difficulty can be roughly graded numerically.

[12] The child's attitude towards the work, needless to say, is a variable condition. For example, on one occasion Robert L. manifests gross inattention, pointing to any of the lights without the slightest relation to the test series. It was necessary to correct the matter by telling him that he was missing every one and that he was not paying the slightest attention to the work. Again, in the case of John P., it was necessary once to interpose. He did well at first but soon began to elaborate his pointing, indicating very carefully and precisely the position of each light, turning his head over to one side and altogether taking several times as long as was necessary; and he would then, of course, forget the last of the series before the first light was sufficiently indicated. He was told that he would do better if he would point faster. Several other similar situations call attention to the unpredictable and largely uncontrollable human factors in any test.

TABLE VII

SCORES ON THREE-LIGHT SERIES ON SUCCESSIVE DAYS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
F.....	8	9	10	9	8	9	10	9	10	9	10	10	10	10	9	10	10	10	10	10	10	9	9	10	9	237
F.....	10	10	9	10	6	10	9	7	10	10	10	9	8	8	9	10	9	10	10	8	8	9	9	10	9	227
F.....	7	9	9	9	8	5	8	8	8	9	9	10	9	10	8	10	10	8	10	10	10	9	9	10	10	222
M.....	5	7	9	8	9	10	9	8	9	10	9	9	10	8	10	9	9	9	10	10	9	9	10	10	10	225
M.....	7	8	9	8	8	5	6	8	6	9	9	10	9	10	9	8	9	9	10	8	9	9	9	10	10	212
M.....	8	10	8	7	9	9	9	10	9	9	9	8	10	8	10	8	10	9	10	9	10	7	9	9	10	224
M.....	6	9	7	7	5	9	8	6	7	8	9	9	10	10	9	10	9	9	9	10	10	9	10	9	10	214
F.....	6	6	5	7	6	7	7	10	8	8	8	9	10	9	10	10	9	8	8	9	9	9	9	10	7	204
F.....	9	10	7	6	7	9	8	10	9	8	9	8	8	7	6	8	7	7	7	7	9	6	5	8	9	194
M.....	6	8	10	8	6	4	8	7	4	6	9	7	7	8	9	8	6	9	9	10	10	8	8	8	8	191
M.....	6	8	8	6	7	7	8	6	6	7	8	4	9	5	4	6	8	7	9	8	9	7	6	6	8	173
Total	78	94	91	85	79	84	90	89	86	93	99	93	100	93	93	97	96	95	102	99	103	91	93	100	100	

TABLE VIII

SCORES ON FOUR-LIGHT SERIES ON SUCCESSIVE DAYS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
F.....	5	9	8	7	8	7	10	10	6	6	8	7	6	9	9	10	9	8	10	10	9	9	10	7	9	206
F.....	6	6	7	5	6	6	6	7	9	7	8	10	5	8	6	7	8	9	7	9	6	10	9	6	8	181
F.....	2	6	4	6	6	5	8	5	6	8	9	10	8	8	4	9	6	10	8	10	7	7	8	10	10	180
M.....	3	1	5	1	4	9	7	8	8	8	7	6	6	5	6	8	9	8	9	9	7	8	7	9	9	167
M.....	3	2	6	6	5	8	7	7	9	6	9	6	6	9	9	7	5	7	9	8	9	7	7	8	9	174
M.....	5	7	3	4	1	3	4	7	6	5	8	6	6	9	8	8	6	7	7	5	7	8	8	9	8	155
M.....	3	5	6	3	4	7	5	5	7	4	8	5	4	8	7	8	9	6	7	7	7	8	8	7	8	156
F.....	2	3	3	4	6	1	3	4	6	3	5	9	7	7	4	8	8	8	6	7	8	4	8	6	8	138
F.....	6	6	2	2	4	5	8	6	4	5	6	6	6	3	4	4	5	5	7	2	6	2	6	6	5	121
M.....	2	1	3	4	2	4	1	4	5	5	4	4	8	4	7	6	3	8	6	4	7	3	6	4	5	110
M.....	2	4	3	2	1	5	1	5	3	0	3	3	3	1	3	3	4	4	2	4	3	1	4	3	6	73
Total	39	50	50	44	47	60	60	68	69	57	75	72	65	71	67	78	72	80	78	75	76	67	81	75	85	

experiment. The sex of the subject is indicated by F or M and the subjects are ranked in order of efficiency in the total performance (3 and 4 combined). The figures indicate the actual score of a child on particular days. The maximal score on any day is ten.

If individual learning curves be plotted, some show a marked practice effect, and others show relatively little change with practice. When we consider the total daily scores for the group as a whole there is clearly a gross learning effect. The total scores have been plotted in Fig. VI. They show beyond question that practice increases efficiency in the performance studied.

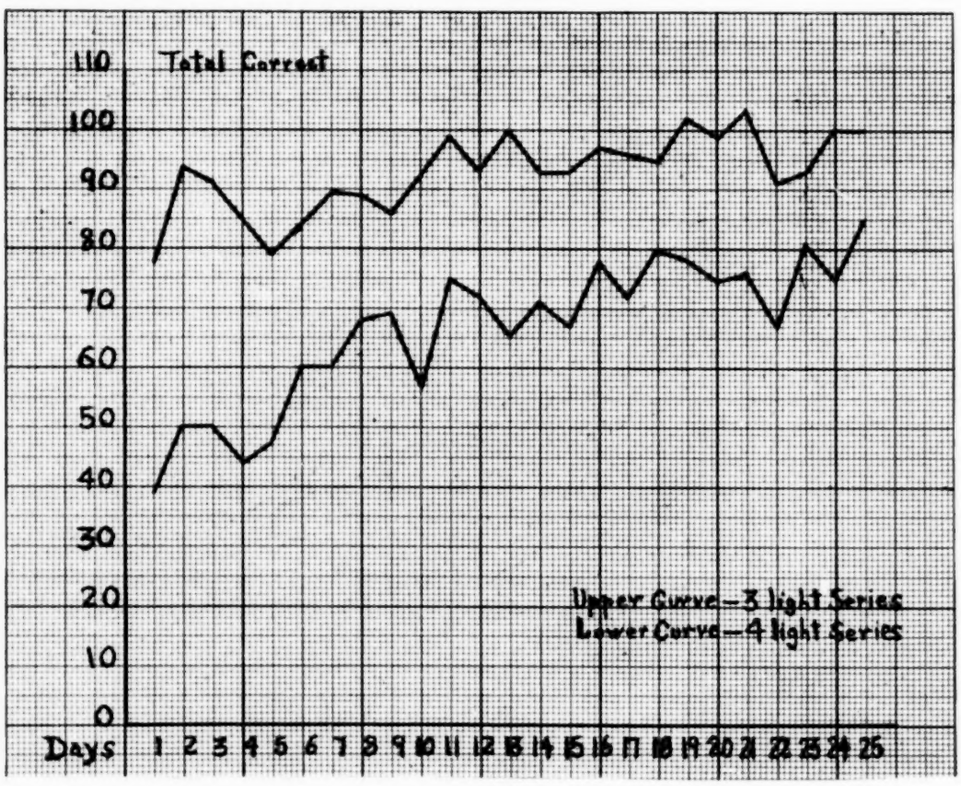


FIG. 6.

The learning curves give the impression that improvement is more marked with four-light than with three-light patterns. If we take the first five and the last five trials together, we have the following percentages:

	Per Cent. of Total Trials Passed		% Improvement
	Periods 1–5	Periods 21–25	
Three-light tests	77%	88%	11%
Four-light tests	41%	67%	26%

If we consider these percentages as absolute values, it is true that Test 4 shows greater improvement than 3 (26 per cent. against 11 per cent.). If we consider these percentages relatively, the case is different. Test 3, with 77 per cent. correct at the start, had a possible improvement of 23 per cent.; and the actual improvement was 11 per cent., or nearly 1/2 of the possible improvement. Test 4, with 41 per cent. correct at the start, had a possible improvement of 59 per cent.; and the actual improvement was 26 per cent., or slightly less than 1/2 of the possible improvement. Hence, relatively speaking, improvement on Tests 3 and 4 is about the same: both curves rise about 1/2 of the possible distance.

Between the first and the last practice-period four months elapsed and the children, therefore, were 1/3 year older at the close than at the beginning of the experiment. This amount of maturation can not in itself account for the marked increase in efficiency shown by the practice curves (see Figs. II and III).[13]

The test described in Part I was given at three different times to the practicing group[14] with the following total results in percentages:

Test Number	Prior to Practice	After 14 Practice Periods	After 25 Practice Periods
2	100%	100%	100%
3	70	88	93
4	36	59	84
5	5	18	36
6	0	0	2
7	—	—	0

[13] It is difficult to estimate the amount of improvement which may be referred to maturation. The difficulty lies in the fact that the performance of the present group at the start was better than our expectation based upon the tests of six-year children in the previous study.

In the work of Part I six-year-old children passed 56 per cent. of the total three-light patterns and 22 per cent. of the total four-light patterns. In the present study the children passed, on the first practice period, 71 per cent. of the three-light and 35 per cent. of the four-light series.

This difference may be fortuitous, depending on the chance selection of rather small groups. The difference, however, may be referred to experimental conditions. Specifically, in the work of Part I the procedure was rather matter-of-fact whereas in the present study the child was given a certain amount of encouragement. Also the experimenters of Parts I and II are of different personality. It is quite possible that such factors as incentives, personality of the experimenter, 'cheerfulness' of the experimental room, etc. are significant conditions of performance.

[14] The procedure in giving the test has been described by Mr. Gundlach as follows:

See that the subject stands in front of the apparatus at arms-length. Then proceed: "I have here some little lights which I can turn on." [Play series 640.] "Now I want you to take this pointer and, after I light some of them, I want you to point to them in just the same order as I turned them on. Like this." [Play series 827 and then point to them.] "Do you see? Now you take the pointer. Remember, do not point until the lights have stopped; and be sure to point in just the same order in which they came on. Let's try two lights first." [Play 40 and then 04.] If the subject gets the order wrong in either series, say: "Oh, but that one did not go on

Thus it appears that in every test there is a marked improvement. The test, however, was repeated in precisely the same form at three times and it is clear that learning of the test-material through repetition may account for the improvement. To check this possibility a control-group of nine subjects was employed.

The control-group received the test at intervals corresponding to those of the practicing group, but between successive tests the controls received no practice. The total percentages for the control-group (nine subjects) are:

Test Number	First Trial	Second Trial	Third Trial
2	97%	100%	100%
3	72	86	92
4	33	52	64
5	2	8	14
6	0	2	0
7	—	0	—

The increase in percentages passed with successive repetitions of the test is very marked. This strongly suggests that learning of the test itself is an important factor in the improvement shown by the practicing group. With Test 3 the control group improved practically as much as the practicing group. On the more difficult tests, however, with four and five lights, it is clear that the practicing group shows *relatively* greater improvement in the performance than the non-practicing group. It is of interest that the practicing group shows improvement on Test 5 which was not specifically practiced. The lines, angles, triangles and other patterns which occur in 5 were undoubtedly practiced in the series with three and four lights.

Conclusion. With six-year-old children practice in the type of performance which is examined in the present study increased efficiency. This increase is shown (*a*) by practice curves, and (*b*) by a change in the scores of the test described in Part I.

PART III

The Factor of Time

Following the work of Part II a special study was made in the laboratory to answer the question: How does efficiency in the present test vary with the rate at which the lights are presented?

The speed of presentation was systematically varied, maintaining (*a*) equal durations for every light in a particular presentation, and (*b*) zero interval between successive flashes. Ten speeds were selected for study: .1, .2, .3, .4, .5, .6, .7, .8, .9 and

first! Try it again!" Repeat the series. Then say: "Fine! Now let's try three lights. You can do three, can't you?" [Play series 876 and then 687.] Correct the subject not more than one time on either of these series. Then say: "All right! Now let's do some more with two lights." Present the two-light series of the test. "Fine, now here are some with three. Try hard!". And so on throughout the test.

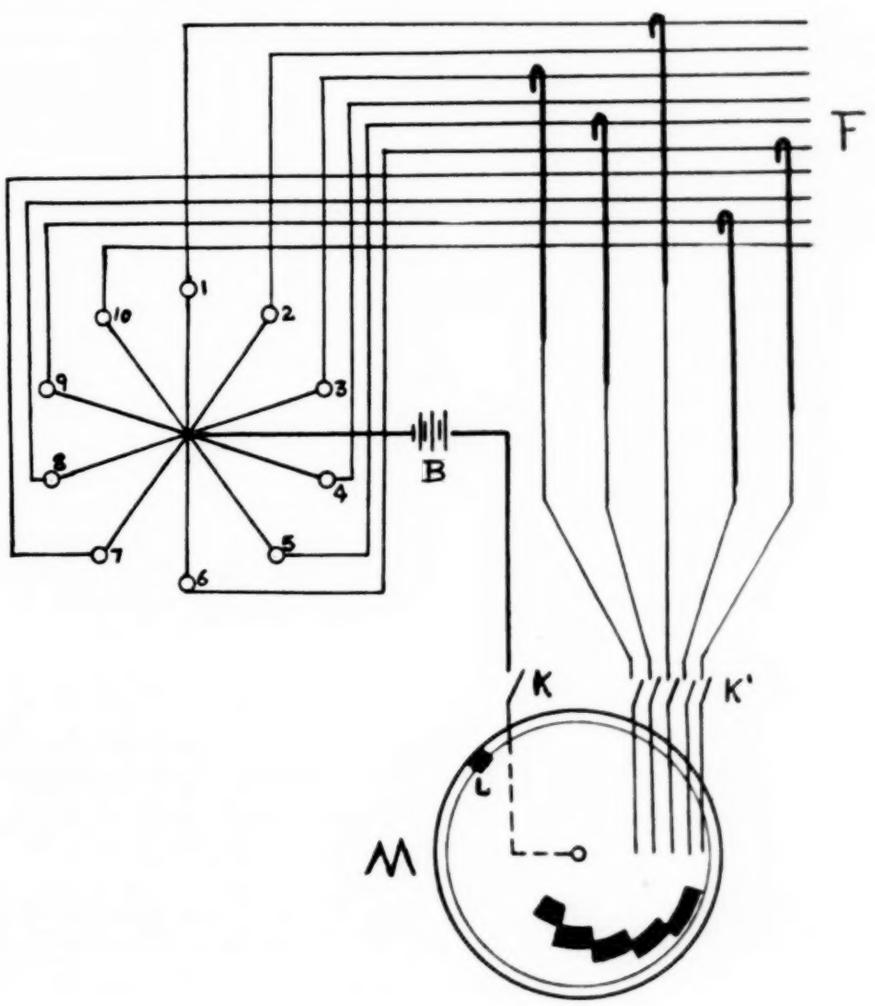
1.0 seconds. These figures refer to the duration of a single light and since there were five lights in every presentation the total times of presentation were five times the above values.

The experiment was limited to five-light combinations since the work of Part I revealed that these combinations were of average difficulty for adults. Prior to the experiment chance series of five-light combinations were determined in a manner previously described (footnote 11). Every combination differed from every other, and in a particular combination no light occurred twice.

Three men (McD, T, W) and one woman (G) served as subjects. The subjects worked two half-hour periods a week, in the late afternoon during April and May of 1926.

Each subject received first ten trials at the speed of .1 sec (per light) and then ten trials at the speed of .2 sec and so on up to ten trials at the speed of 1.0 sec. This total series of 100 trials was repeated five times, making 500 trials per subject in the experiment. On a single experimental day each subject completed on the average 60 trials, *i.e.* six speeds.

Apparatus. A schematic diagram of the apparatus, showing electrical connections, is presented herewith.



Time was controlled by a phonograph motor (*M*) which rotated a polished brass plate beneath five contact brushes. Thin cardboard discs were inserted between the plate and the brushes for purposes of insulation, and sectors were removed from the discs to give the desired duration and sequence of electrical contacts between plate and brushes. The cardboard discs were fastened by means of a peg (*L*) so that they rotated with the same angular velocity as the plate itself.

Prior to the experiment the rate of the motor was determined and, for a period of two weeks, it was found to be practically constant. During the experiment, however, the motor slowed down progressively—at first only a little and then with acceleration. Consequently the times presented in the following tables are not quite constant.[15]

The ten lamps of the apparatus were connected to wires stretched horizontally and in parallel upon a frame (*F*). The space of an inch was left between every two consecutive wires. Upon this frame were five heavy copper hooks, electrically insulated except at the tip. These hooks were connected by long flexible wires to the contact brushes. The hooks could be quickly hung on the parallel wires, thus controlling the combination of lights in any presentation.

The phonograph motor ran continuously during the course of an experimental period and the flashing of lights in a particular test was controlled by means of keys inserted in the circuit. For durations over .4 sec the sectors in the discs were so long that the total required more than 360°, and to prevent simultaneous flashing of lights silent keys (*K'*) were put in the circuit. These keys were controlled by hand so as to give only one light at a time. A little practice was necessary to control these keys properly. For the shorter times (.4 sec and less) these five keys were closed and a master-key (*K*) was used to make and break the circuit.

Procedure. The subject was seated before a neutral gray screen upon which the ten holes presented the form of a circle. Behind the screen on a table was the apparatus for controlling

[15] The rate of the motor was determined once a week and generally twice a week during the course of the experiment. In the following data the duration "one second" has the following time values:

At the close of series	1	1.05 sec
" " " " "	2	1.08 "
" " " " "	3	1.11 "
" " " " "	4	1.19 "
" " " " "	5	1.30 "

The actual time values for the fractional parts of a second are correspondingly less. For example, the value we have called .1 sec actually varies between .10 and .13 sec.

Fortunately our experimental results are so gross that this variation in time does not make any significant difference.

The difficulty with the timing device is that the motor was made to move too slowly for constant speed (1 rev. in 2 sec). In view of the failings of the apparatus I would recommend for further work the use of some device with a pendulum control.

the time relations and the sequence of lights. One experimenter (G) controlled this apparatus and gave the customary 'ready . . . now' signals. A second experimenter (Y) sat at a table behind the subject where he observed and checked the sequence of lights as they were presented, recorded the positions indicated by the subject, and made a record of the subject's comments.

At the beginning of every experiment the subjects were asked to read the following general instruction:

After the signals 'ready . . . now' five lights in succession will be flashed before you. The rate will be constant for any presentation. Several rates will be employed during the experiment.

Observe attentively the flashing of the lights, noting especially the position of the lights and their sequence. After the last light has disappeared, point *in order* to the places where the lights appeared.

Try to maintain a normal, uniform attitude towards the entire experiment. Do not trouble about your failings in the experiment.

You are asked to make comments about the performance. State anything and everything which seems to you significant or possibly significant. It is hoped that your comments will throw light upon the nature of the performance here studied. Comments may be made at any time you desire during the entire experiment.

Data. The raw data are presented in Tables IX–XII. Each table shows the number of errors made by a subject at every speed of presentation. Each row is totaled to show the number of errors, out of a possible 50, for a particular speed of presentation.

TABLE IX

SUBJECT G

Time in Seconds	Total Errors in Series 1–5					Totals
.1	8	8	9	9	5	39
.2	7	5	6	6	3	27
.3	8	6	2	4	2	22
.4	6	5	2	4	2	19
.5	7	3	2	3	1	16
.6	3	1	4	1	0	9
.7	4	4	0	1	2	11
.8	4	4	0	0	0	8
.9	4	3	2	1	0	10
1.0	4	1	1	1	1	8
Totals	55	40	28	30	16	169

Inspection of the tables shows that efficiency in the test varies with the exposure time. The shorter the time the

TABLE X

SUBJECT McD

Time in Seconds	Total Errors in Series 1–5					Totals
.1	9	10	8	9	9	45
.2	8	10	8	8	8	42
.3	9	6	6	7	5	33
.4	10	6	7	7	5	35
.5	10	9	8	6	9	42
.6	10	7	9	8	5	39
.7	10	8	4	6	3	31
.8	9	5	7	6	3	31
.9	7	5	6	6	3	27
1.0	8	9	7	7	3	34
Totals	90	75	70	70	53	358

TABLE XI

SUBJECT T

Time in Seconds	Total Errors in Series 1–5					Totals
.1	9	6	6	6	8	35
.2	5	3	2	1	1	12
.3	4	1	4	1	1	11
.4	2	2	1	2	0	7
.5	4	1	1	0	2	8
.6	5	1	0	0	1	7
.7	0	0	0	2	1	3
.8	0	1	1	0	0	2
.9	0	0	0	0	0	0
1.0	1	2	0	0	1	4
Totals	30	17	15	12	15	89

TABLE XII

SUBJECT W

Time in Seconds	Total Errors in Series 1–5					Totals
.1	7	8	8	9	8	40
.2	4	4	2	5	4	19
.3	9	3	4	3	1	20
.4	7	3	2	3	2	17
.5	3	6	4	3	4	20
.6	4	1	4	2	3	14
.7	5	3	4	3	1	16
.8	2	1	3	1	4	11
.9	2	0	2	3	2	9
1.0	2	1	1	1	0	5
Totals	45	30	34	33	29	171

greater the number of errors. The total errors for the four subjects are given below:

Time (sec)..	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Errors.....	159	100	86	78	86	69	61	51	46	51

The curve is fairly regular. It is impossible to say whether the rise in the number of errors at .5 sec has any significance or whether it is fortuitous.

The totals at the bottom of the columns indicate errors made in each series of 100 trials. An effect of practice is clearly shown by these totals. For the four subjects together the total errors on successive series is:

1st	2d	3d	4th	5th
220	162	147	145	113

This practice curve for adults confirms the conclusion of Part II with six-year-old children.

If we consider the practice curves for each time separately, we find, totaling the four subjects, that the effect of practice is relatively slight at the speed of .1 sec and appears to have a maximal effect at the speed of .3 sec.

Since the trials at the different speeds were given in a serial order, it is clear that the lower rows of the tables, with longer durations, presuppose more practice than the upper rows with briefer durations. Part of the variation which we have attributed to the time factor may, therefore, be attributed to practice. Actually, however, the error is slight if we assume that each row represents the same amount and distribution of practice.

It is interesting to note that the subjects differ markedly in the total number of errors made. McD makes 358 errors. W and G are about equal in performance, W making 171 and G 169 errors. T makes fewest errors, 89. What these differences indicate is a question which would take us too far afield.

Conclusion. Efficiency in the present test varies with the speed at which the lights are presented. In general, the faster the speed the more erroneous the performance.

Practice markedly increases the efficiency of performance with adults.

PART IV

Analysis and Discussion

Reports of the Subjects. We have reports from three sources: (A) While the work described in Part I was in progress an analysis was begun in the Psychological Laboratory. The apparatus, speed of presentation, procedure and other experimental conditions were the same as those in

Part I except that the subject was not warned in advance of the number of lights in a particular series and, further, that the experiment was limited to combinations of 3, 5 and 7 lights. There were four subjects[16] and each made seven reports. Excerpts from the reports are given below.

Subj. A. (7) A grouping of the two on the left which were in line; then directly across and down, the fourth being out of place. I am uncertain about the last three. Position was carried mostly in visual terms. I went back at the end of each group and clinched them. This distracted from the last three.

(3) The speed is too slow. After each light is flashed I find myself building up association lines between the last and the one previously flashed.

(3) A visual triangle, and the triangle didn't come until the end of the third one. Not even a line before.

(5) The first three made a visual triangle. At first a line and then another line. The others were not organized and seemed to disrupt the first figure. The first three were in visual terms and the next two were kinesthetic.

(5) The first three, a visual triangle. The only verbal comments were 'there, there, there,' and the comment 'triangle.' A pointing with the finger.

Subj. H. (7) I drew lines and squares. The first four formed a square but after that I wanted to group them into a 3-3-1 arrangement. There was a feeling of relief when it made a square.

(5) After the second light I remember the positions. A figure of a short triangle and a large one. When the lights cross they bind each other together.

Subj. G. (7) The first four fell into a visual and kinesthetic pattern. The formation interfered with the apprehension of the other three. The period of reproduction was characterized by visual imagery and kinesthetic processes for the first four. For the last three there was obscure kinesthetic and visual imagery. Reproduction uncertain.

(3) Kinesthesis of the eyes. Before the third, there seemed to be filled in an imaginary triangle. I was expecting a triangle. Reproduction started by a memory image of the first and by kinesthesis and visualizing.

(5) The perception was of two periods, a visual and kinesthetic grouping of the first three into a triangle and of the last two by a line crossing the triangle. Reproduction was under the influence of these groupings.

(5) The series was apprehended as a whole. Tied together by visual kinesthesis and bodily movements. The performance was automatic. 'There, there, there' (verbal) with the bodily kinesthesis.

Subj. Y. (7) When the lights flashed a tendency to follow with the head and eyes which came as a pressure in muscles. Relationship was retained by kinesthesis in neck, eyes and shoulders. The relationship was a gesture of six movements which I reproduced. A tendency to visualize was bound up with these pressures.

(5) Tendency to follow with eyes and head. The position of the first light relative to the board was noted. The second light was related both to the board and to the first light. There was an imaginary line connecting them. The third formed a

[16] The subjects were Misses Harriett M. Anderson and Lillien Hatfield, Messrs. C. R. Griffith and P. T. Young.

triangle. The next two were taken as a separate unit. The position and direction of the line were noted. Upon reproduction I pointed to the triangle and then to the other two.

(5) In this case my eyes followed the flashing lights so that there was a movement of the head and eyes as each light flashed. The five were taken as a unit. A tendency to note the relation of the lights to the board but I noted chiefly the relative position of the points. A continuous path making a pattern of imaginary lines down, up and across. The lines make a unit.

(7) Feeling of complete uncertainty. I know I missed. At the start the flashing lights took my eye. Definite following of the lights with head and eyes. The first three make the corners of a square but the fourth made a corner a little too high. I am certain that the first four were correctly reproduced. The last three formed a group. The whole was a group of four and another group of three. When it was over I felt that I could do it; but while I pointed to the first four the last three faded out.

(1) From the reports of the subjects it appears that the successive lights are grouped into lines, triangles, squares and other patterns. Sequences of five or seven are sometimes broken up into two or three patterns, and a second grouping of the lights may disrupt an earlier one. The subjects speak of a 'clinching' or 'binding together' of the material. (2) Kinesthetic processes of eyes, head, arms, *etc.*, are reported. These processes may be rhythmical and they are sometimes related to the visualizing of the figure. (3) Inner speech, reviewing and other secondary aids are reported.

(B) A second analytical study was made at the close of Part III. Two psychologists served as subjects: Drs. Elizabeth Möller and Alice H. Sullivan. Experimental conditions were the same as in Part III except that the subjects were instructed to make complete psychological analyses of their experiences and that not all of the speeds were used. We specialized on the shorter speeds. Each subject gave 50 reports, 5 each for the following speeds (sec): (day 1) .1, 1.0, .2; (day 2) .9, .3, .1, .5; (day 3) .7, .1, .4. The subject was always forewarned whether a speed would be slow or fast. Significant parts of the reports are given below:

Subj. M. I fixate the center and attend to the periphery. The experience is held in terms of kinesthesis. That was definitely done in terms of eye kinesthesis (.1).—Definite eye movements from first to second. Fragmentary kinesthesis which meant 'this one there.' I resuscitate those eye pressures and translate them into the kinesthesis of pointing. Throat kinesthesis described the relation of the second to the first and of the fourth to the fifth 'across, line, below' (1.0).—Attention is spread out around the periphery with fixation at about the center of the circle. I don't like these fast

ones. A hint of eye movement with no throat kinesthesis. No time to pick out cues. I tried to reproduce as quickly as possible before the eye pressures died out (.2).—I tried that time to hold the visual pattern and that was a failure. I didn't get the right set.—A lot of pressure-strain about the eyes particularly during reproduction.—Whenever possible there is added to the eye pressures some throat kinesthesis which serves as a cue.—I noticed from the first to the second you skip two lights.—At the start fixation in the center. Then definite eye movements from first to second and the relationship was noted in voci-motor 'skip one.' Symmetrical form noted. When the second came it meant 'a straight line.'—I fixated the center and attended to the periphery. As the lights came I didn't ever look directly at any one. The eyes flickered just a little bit towards the lights. Never full eye movement. Eye pressures when I reproduced. I knew the right light was out in that direction (.3).—I don't know how I got that. I reproduced by eye kinesthesis. A pressure meant 'down,' another meant 'up,' etc. I follow these pressures (.1).—The experience is too rapid for throat kinesthesis to be of any use and if there is eye kinesthesis I didn't notice it.—The actual experience is translated into kinesthesis. A sweep and a jerk meant a light. Also voci-motor aids (.5).

Summary of M's reports. With the fast rates fixation is in the center of the board and there is a spread of "attention" over the periphery. There are incipient eye-movements revealed by pressures about the eyes which pressures serve as cues for reproduction. With the slower rates there are successive fixations. Spatial relations are noted verbally.

Subj. S. It seemed to remain as a memory after-image for a short time (.1).—I fixated the center of the circle and kept on fixating. When the lights came I got slight eye movements but didn't let the eyes follow. The lights came in peripheral vision. I noticed throat kinesthesis 'hum . . . um . . . um . . . um . . . .'—With the first three lights I get an experience much like a memory after-image. That fades about the time the fourth light comes on and that confuses me (1.0).—That was easier because I followed the lights with arm kinesthesis as if I were pointing. There was a memory after-image and possibly also a positive after-image. I constructed an imaginary triangle for the first part.—Throat kinesthesis that counts and helps place them. I noticed after-images which connected up with streaks of light. Throat kinesthesis like 'there . . . there . . . there . . . .' That was decidedly rhythmical (.2).—It is more difficult with the slow ones. Not so easy to connect them up in one figure. The memory after-image dies out. Rhythmical throat kinesthesis. Eye movements. That was easy. It made a right triangle. The eye movement carries the meaning of some kind of figure. I don't *see* any figure (.9).—That time I constructed two kinds of units. One was visual with eye movements and the other was with throat kinesthesis.—Made a pattern which was easy to reproduce. I find myself counting with stress on the third and fifth (.3).—There are two ways to do this. You can follow each light as it comes on, or you can stare at the center and get little movements. That's what I did. Eye movements carried the meaning of direction. Counting and stressing in throat kinesthesis. I direct my attention to the first and third to remember them. I don't attend as well to the fourth and fifth. The last two are not so clear as the first and third (.5).—The relation is carried in eye kinesthesis and if the lights are adjacent, I get the same kinesthesis and then confuse them. If

not adjacent, they are clearer and I don't confuse them because they demand more attention and more eye movement.—A strong feeling of direction which could be analyzed into throat kinesthesis (.7).

Summary of S's reports. For the fast speeds S fixates the center of the board, getting the lights in indirect vision, and for slow speeds successive fixations are made. S reports images, especially memory after-images, which are clearer at the faster speeds. S also notes the process of pattern-forming. Throat and arm kinesthesis, rhythmical accents and other secondary aids to the performance are reported.

(C) During the work described in Part III comments of the subjects were copied down at the close of every ten trials, and occasionally at other times. The following excerpts have been selected because they seem to throw light upon the nature of the performance here under scrutiny.

Subj. G. I notice after-images; they are very bright (.1).—This is the first one I've tried to follow with my eyes; I look from one to the other (.3).—I didn't follow but fixated the middle of the board. I think at this rate (.4) it is probably better to follow each.—The configuration of lights is more noticeable with the fast than with the slow ones.—Some of these are slow enough to remember by number (.8). [N.B. G knew the lights were numbered for experimental control; the other subjects did not know this. Later G abandoned the use of numbers.] It is hard to get the order. It is as if they go on at once. I fixate the middle of the board and don't follow as the lights flash (.1).—I have much better imagery there (.2) than on the slow ones.—They are too fast to look at each light separately (.3) and too slow to get good imagery.—I notice particularly when the lights are directly opposite and also when they make parallel lines.—I take particular note if the first three go every other one (as 1 3 5).—In some of these I had time to review before I started to point.—They are so slow that my imagery doesn't seem good. It seems almost impossible to get them as geometrical figures (1.0).—I count the lights as they go on. I don't know why. It doesn't seem to help but I do it.

Subj. McD. I have trouble with the order. I am sure which ones come on but not about the order.—Those that follow in order are easier.—I get an after-image, a picture of the whole circle.

Subj. T. There is some visual imagery as if hazy wide indistinct lines connected the dots forming geometrical figures.—There is rhythmical kinesthesis in the throat.—I made, during the exposure, slight movements with the right hand following the course. I thought that helped me.—Some verbal-motor kinesthesis as if counting. If I can get it coördinated with the lights, it is easier.—I tried fixating the center and resisting eye movements and found it difficult to reproduce the motion. I don't feel sure of my results when I do that.—I particularly watch the first four and group them into a geometrical figure. Then the last one is tacked on to that and it is very easy to find the last one.—It seems that when the lines don't cross the images are more distinct. —The patterns seem much easier to reproduce if I consider the spots as ends of lines forming a geometrical figure. If I isolate the points, it is harder.

Subj. W. This time (1.0) they were so slow that it was more difficult than with the faster ones.—There were geometrical figures that helped. Once there were four in succession around the ring and that was particularly easy.—It is bothersome when you change from one speed to another.—I find myself putting the first three in a triangle.—When it jumps across here (.1) it is too rapid for the eye to follow.—When there is no figure it is usually hard to get.—When they alternate back and forth in the same place it is difficult.

(1) The above reports indicate that the subjects frequently form geometrical figures out of the light sequences. Subjective lines are said to connect the lights into a pattern. Spatial relations are noted; parallel lines, adjacent lights, opposite lights, lights in series or in series skipping one, etc. (2) Secondary cues are reported; counting, reviewing, rhythmical kinesthesis in throat, movements with the hand, etc. (3) The performance differs with the speed of presentation. At the speeds of .1 to .3 there is usually a single fixation in the center of the board whereas with slower speeds the eyes follow the lights. The fast speeds (.1 to .3) are said to give better imagery than the slow speeds.

Summary of Reports. Taking the total reports from the above three sources the following conclusions seem justified:

(1) Very frequently a process of grouping is taking place in which separate units are bound together, organized, 'clinched' into larger units. This process of integration appears to the subjects in two ways. (*a*) Visual patterns are formed; triangles, squares, subjective lines, etc. (*b*) There are kinesthetic patterns. The latter are referred to muscles of the eyes, head, arms, and trunk, and they serve as a basis for the movements made during the period of reproduction. This process of integration sometimes breaks a long series into parts both visually and kinesthetically.

(2) The type of performance is not the same at different speeds of presentation. With the fast speeds (.1 to .3) there is usually a single fixation in the center of the board while the lights are seen in indirect vision or with a spread of 'attention.' With slower speeds there are successive fixations. Imagery is said to be relatively clearer with the fast speeds. The slow speeds give time for the use of secondary aids to the performance.

(3) Secondary cues are occasionally utilized by the subjects; inner speech, noting of geometrical relations ('above,' 'parallel,' 'skip one,' etc.), rhythmical movements as 'there . . . there . . . there . . .' in inner speech, incipient pointing movements during presentation, reviewing of the sequence, etc.

Discussion of Experiments

We started out to analyze and test the capacity to become temporarily set. We assumed that the complexity of an instruction which a subject is capable of apprehending and executing indicates his capacity to become temporarily set. In preliminary studies we gave up verbal instruction in favor of the visual presentation of a problem. The flashing of lights, under the general instruction to indicate the sequence by pointing, presents a problem to the subject which sets him in a particular manner. This set conditions his subsequent pointing movements.

In Part I we discovered that the capacity to become temporarily set varies with age. The curves there presented (Figs. II–V), however, are wholly dependent upon conditions. With practiced subjects those curves would be nearer the 100 per cent. limit and with a faster rate of presentation they would be nearer the 0 per cent. limit. The extent of change brought about through practice depends upon the rate, being less at .1 sec than at .3 sec per light.

Efficiency in the test varies with age, practice, and the speed of presentation; and the three factors are interdependent. Does efficiency also vary with other conditions? Only further experimental work can adequately answer the question. We make here a few suggestions regarding conditions which demand investigation.

Suppose the subject were forced to delay his reaction for a certain interval instead of pointing immediately as in the present experiment. What variations would be introduced in the numerical results and in the type of the subject's performance? The subjects usually begin to point immediately after the last light has vanished and occasionally they are seen to commence pointing before the last light is extinguished.

It is likely that a forced delay would disintegrate a complex adjustment towards the apparatus. On the other hand, a delay would provide time for reviewing and 'clinching' and might thus preserve the set against disintegration.

The present experiment has been limited not only to immediate reproduction but also to the single presentation of a task. It is clear that with repeated presentations light sequences of indefinite length and of the most complex pattern could be learned. To repeat a task would be to carry the investigation over into the field of learning. The question is here raised: How much of the practice effect which we found in Parts II and III is a matter of the learning of lines, angles, triangles and other figures through repetition? Although a total pattern was never repeated in these experiments, combinations of two and three lights were undoubtedly repeated. Apart from the learning of combinations which enter into the total pattern, is there any genuine improvement in the capacity to become temporarily set? A further investigation is necessary to answer the question.

Another question is this: How does efficiency vary with the spatial arrangement of lights in the apparatus? We have used ten lamps in a circle but there is nothing sacred about this apparatus. (*a*) If the *number* of lamps were increased, there would be more possibilities for error. The number might well be decreased to eight or even fewer lamps (if a light may be used twice in a presentation). (*b*) Other *patterns* might be investigated; *e.g.*, eight lamps in a line, eight lamps on the corners and mid-sides of a square, a wholly irregular pattern, etc. (*c*) The *size* of the apparatus is a factor to be investigated, for the extent of a subject's eye and arm movements, their grossness or fineness, depends upon the size of the apparatus, and these movements are conceivably significant conditions of the performance in the test.

Even such imponderables as temperament of the experimenter, incentives, mood of the subject, 'cheerfulness' of the experimental room, etc., may be significant conditions of performance. We have had a hint of this (see footnotes 12 and 13).

In view of the variability which we have discovered and of the still greater variability which in all probability would be revealed by further investigations, we realize that the capacity tested, in the present case, is nothing fixed and stable but rather something highly plastic varying with this and that condition. When all the significant conditions have been investigated certain ones can be selected as a basis for the standardization of a test. At present an attempt at standardization would be premature.

It is more to the point to raise the question: What are we testing? The reports of the subjects indicate that the type of performance differs with the speed of presentation. With rapid presentation there is usually a single fixation in the center of the board while the lights are seen in indirect vision or with a spread of 'attention.' At slower speeds there are successive fixations. This difference may possibly be only one of degree, but the reports also hint that there is a qualitative difference. Imagery is said to be relatively more clear at the fast speeds and the subjects can rely upon it in a manner not possible with slow speeds. Further, the slow speeds permit incipient pointing movements during presentation, inner speech, reviewing and other secondary aids to the performance which are impossible with rapid presentation. In a word, it is likely that the subject's task is accomplished in functionally different ways at different speeds and even with successive trials at the same speed.

The most precise control of experimental conditions does not guarantee uniformity of performance on the part of the subjects. Uniform tables of test data, as those in Part III, do not imply a corresponding uniformity of function.

A logical and statistical analysis of 'errors' has failed to reveal the simple truth that one and the same 'error' may be made in functionally different ways. Throughout the entire experiment errors were recorded religiously in the hope that an analysis of them would bring to light something of importance. Much good time has been spent in the study of errors, but the result is disappointing and there is nothing worthy of permanent record. The moral is this: a 'mental

test' is not a functional analysis and testing is no substitute for the work of scientific analysis. If we would understand the processes tested in a particular case, we must attack those processes directly.

If we appeal to the psychological literature, we find that the capacity we are studying appears under the title 'memory span.'[17] The present paper might have been given the title 'A Study of Memory Span with Successive Visual Presentations'; but we question the appropriateness of the term 'memory span' and so have retained the title which denotes the original aim of the experiments. It is difficult to see how memory, in the true sense of the word, comes into the present type of performance. On the other hand, the work on 'memory span' is such a hodgepodge that it would be a mistake to substitute such a term as 'set' for the present term 'memory span.'

The capacity we are studying is involved in some of the studies upon 'prehension,' 'immediate memory,' and also in studies upon 'the range of attention,' 'the range of consciousness' and 'the range of apprehension.'[18] These experiments differ among themselves in every conceivable way; in the kind of material presented, in the sense department within which the material is presented, in the manner of presentation, especially whether simultaneous or successive, in the duration of presentation time (a few sigma or a few minutes), in the method of treating the data, etc., etc. The writer has failed to find an adequate functional analysis of the processes involved in the present experiment.

Our main results confirm earlier work. The 'range of apprehension' and the 'memory span' are in approximately the same region numerically as our determinations of the 'complexity of set.' Long ago Hamilton[19] raised the question 'How many objects can the mind embrace at once?' and noted: "By Charles Bonnet the mind is

[17] For references to studies on memory span see J. P. Guilford & K. M. Dallenbach, The determination of memory span by the method of constant stimuli, *Amer. J. Psychol.*, 1925, **36**, 621–628.

[18] For recent work see S. W. Fernberger, A preliminary study of the range of visual apprehension, *Amer. J. Psychol.*, 1921, **32**, 121–133; H. S. Oberly, The range of visual attention, cognition and apprehension, *ibid.*, 1924, **35**, 332–352, and K. M. Dallenbach, Note on Dr. Oberly, etc., *ibid.*, 1925, **36**, 154–6.

[19] W. Hamilton, *Lectures on metaphysics and logic*, 1859, **1**, 176–177.

allowed to have a distinct notion of six objects at once; by Abraham Tucker the number is limited to four; while Destutt-Tracy again amplifies it to six." Hamilton places his estimate at six and writes: "If you throw a handful of marbles on the floor, you will find it difficult to view at once more than six, or seven at most, without confusion; but if you group them into twos, or threes, or fives, you can comprehend as many groups as you can units; because the mind considers these groups only as units,—it views them as wholes, and throws their parts out of consideration."

The early work on 'prehension' brought out clearly a relation between this capacity and age. Jacobs[20] pronounced a series of nonsense syllables and other materials at a 'convenient rate' and asked the subject to reproduce the material. He found a relation between length of series and age as follows:

Age	11	12	13	14	17	18	19	20
Number of subjects	3	7	11	9	12	13	6	2
Ave. no. of syllables	5.3	5.3	5.7	5.2	5.7	6.1	7.2	7.0

Jacobs noted that the span varied with the material used. "Thus a number of school-girls who could repeat on an average 6.1 nonsense-syllables could repeat 7.3 letters and 9.3 numerals." Bourdon[21] asked subjects to repeat after him digits, letters, monosyllables and words with two and three syllables. He used series of 4 to 8, and with about 1/2-sec interval between successive units. He concludes that immediate memory increases from 8 to 20 years, chiefly from 8 to 14 and not sensibly from 14 to 20.

That practice increases efficiency in visual apprehension has been reported by Whipple, Foster, Dallenbach,[22] and others. The method of these studies is so different from our own that it is a question whether a direct comparison is justifiable.

The traditional concepts of 'attention,' 'apprehension,' 'memory span,' etc., have been generally ignored in the present study for they too frequently serve to cover up ignorance and to obscure problems. The concept of 'set' has the advantage over these terms that it denotes a demonstrable biological process which is capable of exact physiological analysis. The concept also places the emphasis upon the organism rather than upon pictures, ink dots, nonsense syllables, and other objects.

[20] J. Jacobs, Experiments on 'prehension,' *Mind*, 1887, **12**, 75–79. Galton supplemented Jacobs' work with a few observations on idiots and found their prehension span noticeably less than normal, *ibid.*, 79–82.

[21] B. Bourdon, Influence de l'age sur la mémoire immédiate, *Rev. phil.*, 1894, **38**, 148–167.

[22] G. M. Whipple, The effect of practice upon the range of visual attention and of visual apprehension, *J. Educ. Psychol.*, 1910, **1**, 249–262.

W. S. Foster, The effect of practice upon visualizing and upon the reproduction of visual impressions, *ibid.*, 1911, **2**, 11–22, and K. M. Dallenbach, The effect of practice upon visual apprehension in school children, *ibid.*, 1914, **5**, 321–334; 1919, **10**, 61–82.

The concept of 'set' raises many questions for further experimental analysis. It is suggested that future work be based upon a consideration of the phases and aspects of set revealed in the present study. Five important phases are noted below. (1) The general experimental instruction 'to observe and to point to the lights in sequence' is carried over from day to day as a neural set. The child does not need to be instructed daily (Part II) but assumes an attitude towards the apparatus which presupposes learning. (2) After the signals 'ready . . . now' the subject has ordinarily assumed a characteristic bodily posture before the apparatus. This phase presents a neuromuscular set *to see*, which is conditioned by the total experimental situation. (3) During the phase of presentation a process of integration, organizing, binding together, is reported. At the close of the presentation a temporary neuromuscular set is established. It is necessary to distinguish between relatively simple and relatively complex adjustments. (4) After presentation of a problem, task, or instruction, the set is retained. We have not studied the interval between presentation and performance. (5) In the final phase the set conditions the sequence of pointing movements and then apparently vanishes; although something is doubtless retained as neural organization.

Every phase and aspect of the performance presents problems for further experimental analysis.

AN APPARATUS FOR ACUITY, FOR MIXING COLORED LIGHTS, AND FOR TESTING THE LIGHT AND COLOR SENSES

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Several requirements have served as an incentive for devising an apparatus of the kind to be herein described. (1) There is a great need for determining acuity over a wide range of intensity of illumination. Eyes rated the same or approximately the same at high illuminations, *e.g.*, may be rated very differently at low. In rating eyes for vocational fitness, therefore, they should be tested as nearly as possible at the intensity of the work to be carried on. The Navy has felt this need in the selection of its men for the look-out work at night and the Air Service in its selection of night fliers. Furthermore, there is need to provide for testing at low illuminations in the diagnosis of errors of refraction by the acuity method. Smaller defects of refraction and smaller errors in the correction of a defect can be detected at low than at high illuminations.

Two reasons may be given: (*a*) The focussing power of the contracted pupil at high illumination prevents a great deal of the blurring of the image that would occur with the same defect of refraction with the moderately expanded pupil found at the lower illuminations, and (*b*) a part of the blurring due to the error of refraction is compensated for by the greater power of the retina to discriminate detail in high lights. What we have called the superior focussing power of the pupil at high illuminations is due to the fact that the small pupil narrows the beam of light which emerges from each point in the object and which must be brought back to a point in forming the image, and thus reduces the size of the diffusion circles due to faulty focussing. The effect of the small pupil is to mask the defect so far as the influence on clear seeing is concerned, and therefore to lessen the ability to detect it by means of any test based on clear seeing. Neither is a pupil too widely expanded desirable. By throwing into function the refractive defects usually found in the periphery of the lens, it causes too great a blurring of vision to permit of the best possible sensitivity in the use of any test based upon clearness of seeing.

(2) If a convenient means is provided for changing the intensity of illumination in a continuous series or in finely

graded steps, the illumination scale as an indicator or detector may be combined to advantage with the visual angle scale in the correction of errors of refraction by means of the acuity test.

For example, when the 6/5 line on the chart has been read and no correction can be made that will permit of the reading of the 6/4 line or any part of it, many steps may be inserted between the acuities represented by these two lines at a given intensity of illumination by reducing the illumination in small steps. In such a case the glass which enables the reading of the 6/5 line at the lowest illumination should be accepted as the best correction.

(3) Intensity of illumination and a convenient and accurate means for its control are important factors also in the use of charts for astigmatism. While, as stated above, the acuity test is much more sensitive at low than at medium and high illuminations for the detection or correction of errors in refraction, the converse is true, *e.g.*, of the radial line chart for astigmatism. Such charts can be used with much greater sensitivity for determining the amount of an astigmatism or the exact placement of its correction at high than at low or moderate illuminations. (Details and explanation will be given in a later paper.)

(4) There is a further requirement, both in laboratory and clinic work, for an instrument by means of which small changes may be made in the size of a variety of test-objects of the more improved types; also for a provision in the same instrument for varying in sufficiently small amounts the intensity of the light by which these objects are illuminated.

Such an instrument would present the possibility of using the visual angle and the illumination scales in separation or in conjunction as the needs of the work require. Also charts of the Snellen type could be used, or single test objects, such as the broken circle, the opening of which could be turned at will in different directions in order to impose an objective check on the judgment. When provided with these controls, too, the broken circle can be used with great facility in the very sensitive test for astigmatism described by us a few years ago (1); the one to provide for the different sizes of test object needed for eyes of different acuities, the other to give the small variations in light-intensity needed to detect the differences in the resolving or image-forming power in the normal and astigmatic meridians.

(5) Length of exposure also is an important factor in the results obtained with the acuity test. Unless the length of exposure of the test-object is subjected to control a close

reproduction of results for any given set of conditions can hardly be expected. Moreover, when needed, great sensitivity can be added to the acuity-test by decreasing the time of exposure. The limit of this procedure is reached when the minimal amount of time required to discriminate a given detail is determined. The result thus obtained is called the speed of vision, one of the eye's most important functions. It is of paramount importance in rating the eye's fitness for various vocational uses and it affords an extremely delicate means of differentiating between favorable and unfavorable working conditions for the eye. Its diagnostic value has already been indicated. It should be given a prominent place in any program of visual tests.

And (6) there is a need, particularly in office and clinic, for a feasible and quick means of determining achromatic and chromatic sensitivity.

The apparatus devised by us to satisfy these and other requirements has the following features. (1) Any acuity object, acuity chart, astigmatism chart, or other test surface within certain limitations of size, may be uniformly illuminated over its entire area and the illumination varied in finely graded steps from high to low without any change in the color of the illuminating light. (2) By means of a slight modification quickly made, the apparatus can be converted into a device for changing in small amounts the size or visual angle of the test-object over a wide range. This change can be made throughout the entire range, if desired, without any change in the intensity of the illuminating light; or the illumination for any size of test-object can be varied from high to low in a continuous series without any change in the color of the illuminating light. (3) By means of shutters similar to those used in photographic cameras the length of exposure of the test-object can be held constant or varied over a considerable range. And (4) the apparatus may be used to test the light and color sense. It also may be used as a mixer for colored lights obtained from filters and as a device for varying independently their saturation and brightness.

The need for evenness of illumination in testing acuity is obvious. Important for making the test at any intensity, it becomes a necessity at the lower illuminations because of the increased effect of differences of intensity on acuity at these illuminations. The even illumination of a test-chart has been, we scarcely need to point out, one of the traditional problems of acuity testing. While it is difficult, if not impossible, uniformly to illuminate a surface of any considerable size directly or indirectly from one or more sources of light, it is not especially difficult to illuminate evenly a surface of small size by devices which are feasible and to project the magnified image of this surface on a larger one. This principle is used in the present apparatus. A small aperture of the desired shape and dimensions is illuminated uniformly and its magnified image is projected on the surface to be illuminated. This use of an image for the purpose of illumination paves the way also for the solution of the second problem; namely, the obtaining of finely graded changes of intensity without change in color of light. That is to say, any variation in the size of aperture of the projection-lens employed changes the intensity of the light in the image formed without altering the evenness of distribution of light or changing the size or shape of the image. A convenient means of producing regular and known changes in the size of the aperture is an iris diaphragm placed as near as possible to the front or back surface of the lens. The principles outlined here were embodied in an illuminating device which we described a few years ago, called an acuity lantern (2). In the present apparatus the method of applying these principles has been changed for the following reasons. (1) A wider range of intensity was needed than could be obtained with the former apparatus. (2) A form of apparatus was wanted which could be used not only as a means of illuminating over a wide range of intensities existing test-objects and test-charts graded to a fixed scale of sizes or visual angles; but also with a slight modification for varying both the size of the test-object and the intensity of light with which it was illuminated. And (3) for convenience and cheapness of manufacture a

device was wanted which could be used as an attachment or modification of apparatus the parts of which the manufacturer is already equipped to make. Since the Bausch and Lomb Optical Company had arranged for the manufacture of the original apparatus, it was decided to make the enlarged apparatus a modification of the same firm's balopticon. In the modified apparatus, then, the source of light is a high power tungsten lamp. This lamp is placed at the principal focus of a collimating system made up of two plano-convex lenses. At a suitable distance in front of these lenses is a frame in which are inserted, as wanted, plates containing the apertures which are to be imaged on the surface to be illuminated. Between the collimating system and the aperture to be illuminated is a thin plate of ground glass to diffuse the light and to aid in providing the needed uniformity of illumination of the aperture. This plate is placed at a sufficient distance behind the aperture to eliminate all traces of mottling in the image which would occur were its illuminated surface imaged on the test chart. Other features which ensure evenness of illumination of the aperture are (*a*) an etched concave mirror placed behind the source of light which adds a component of diffused light to the collimated beam, and (*b*) the size of the aperture which is so small as to receive light only from a central and more homogeneous portion of the beam. The smallness of size of aperture is due to the fact that the lantern is operated at a distance of 6 meters from the surface to be illuminated. Subjected to the magnification consequent upon this distance, the size of aperture needed to illuminate one or more lines of an acuity chart or even the whole chart is very small. The image is formed on the surface to be illuminated by a projection lens of suitable diopter value. Just back of this lens is the iris diaphragm furnished with a pointer and a scale calibrated in illumination units. A representation of the optical system is given in Fig. 1; a photograph of the apparatus in Fig. 2.

In order to accomplish the second result, change in size of the test-object, the projection principle is also utilized; *i.e.*, the test object is magnified or minified by projection in

order to give the desired changes in size. The test-object is in the form of a lantern slide placed in the beam of light between the projection lens, which should be corrected for

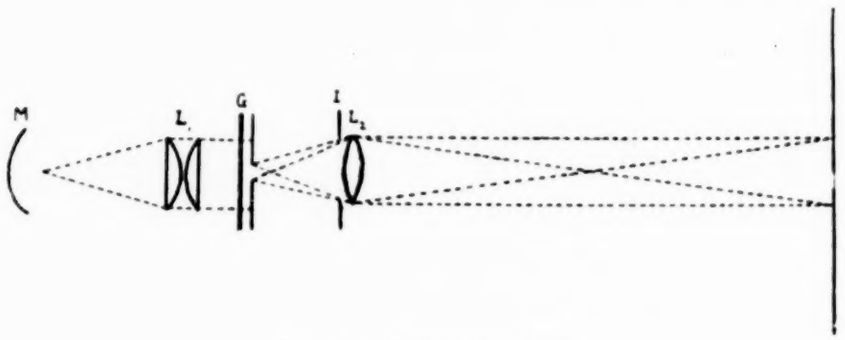

FIG. 1. Optical system

spherical and chromatic aberration, and the aperture illuminated by the condensing system with its diffusing plate. In order that such test-objects as the broken circle may be rotated to present the opening to be discriminated in different directions, the frame which holds the lantern slide is attached to a ring which rotates in a collar. The test-object, however,

FIG. 2. Acuity apparatus

may be anything that is desired, a Snellen chart or any part of it, an astigmatic chart, etc.

In producing changes of size by projection, two problems are presented. (1) The projection must be made with a fixed distance of screen to receive the image; and (2) the change of size produced by minification or magnification of the image of the test-object must be accomplished without any significant change in the light density of the image. In accomplishing both of these features the eye has been used as a model. In the eye (*a*) the retina receives its image at a fixed distance from the refracting system regardless of the distance of the object; and (*b*) changes of size of image produced by changes in the distance of the object do not cause changes of density of light in the image, provided that a constant size of aperture of lens or pupil is maintained. The former of these results, namely a fixed distance of screen from the refracting system, is made possible by changes in the diopter value of the lens as an accommodation for the distance of the object; and the latter is in accord with the following principle. As the distance of the object from the eye is changed both the amount of light entering the pupil and condensing into the image and the size of the image vary in the same relation. Then, as the object recedes from the eye the amount of light entering the pupil decreases as the square of the distance of the object and the size of the image over which the light distributes decreases also as the square of the distance; a corollary of the fixed distance of image and variable distance of object. These compensating changes serve to keep the intensity of light in the image constant as the distance of the object is changed.

In making this statement in reference to the eye we are aware of its approximate character. The law is strictly true only for thin lenses. Its validity is accepted within quite wide limits, however, by the photometrists in the measurement of the brightness of surfaces. Also in our apparatus comparatively thin lenses are used and the changes in the distance of the object are extremely small. The total range of change will probably not exceed 3 or 4 cm.

In order to produce the changes of distance required to give the small changes in size of image needed, the lantern slide-holder is mounted on a slow-motion rack and pinion.

The changes in the strength of lens needed to focus the image on the screen at a constant distance are produced by placing lenses of a suitable gradation of strength behind the focussing lens. The magnitude of change of size produced depends upon the ratio of strength of the projection-lens to that which is added as an accommodation for distance. As this ratio is increased, the size of the steps in the series is decreased, and conversely. The lenses needed to serve the purpose of accommodation may be obtained in stock sizes varying by 1/8 diopter over a considerable range of strengths. They may be rotated into position by a suitable mechanism; or, more simply, they may be dropped into a groove or holder just behind the projection-lens and in close contact with it. By using different strengths of the stock sizes, varying from 1/8 to 1 diopter, for example, in connection with a 5-diopter projection-lens, changes in the size of the image may be produced of the order of 0.02–0.03. By using a larger diopter value of projection-lens these changes may be made still slightly smaller. A finely graded series of sizes can be secured for a single test-object, *e.g.*, the broken circle, the opening of which can be rotated in various directions to impose an objective check on the judgment, by providing certain fixed sizes in the form of lantern slides and filling in between by means of a selected series of lenses. If a Snellen chart, already provided with a fixed scale of sizes, is used as a lantern-slide, small changes in size may be inserted between those presented by each of the lines on the chart by the use of a suitably selected series of lenses. Charts for astigmatism may also be projected as test-objects and their sizes varied if desired in the same scale of relation.

As before, the intensity of light in the image may be varied by means of the iris diaphragm located just behind the projection-lens.

At first glance this might seem to involve a difficulty not present in the use of the apparatus as an illuminating device, namely the influence of the size of the pupillary aperture on the clearness of imaging. This influence is of practical importance, however, only when a blurred image is present. When spherical aberration is eliminated by the use of a corrected projection system and an exact focus is obtained, changes in the size of the pupillary aperture do not seem to change noticeably the

clearness of the image formed. That is, a reduction in the size of the pupil to the point at which diffraction becomes effective exercises a great deal of influence on clearing up an image blurred by spherical aberration, astigmatism, faulty focussing, etc.; but its effect on a clear image obviously should be negligible.

The use of an apparatus of this type for the testing of achromatic and chromatic sensitivity is described in former papers (3). These sensitivities are determined by finding the minimal amount of colorless and colored light needed to arouse the achromatic and chromatic sensation. All that is required for this purpose is to reduce the projected image to the size that is desired and decrease the light to liminal intensity. The reduction in the size of the image is accomplished by reducing the size of the illuminated aperture the image of which is projected on the screen. Colored light is obtained by means of filters inserted in the holder at the end of the projection tube. This holder is provided with three grooves for the filters and with a collar which slips over the end of the projection-tube. The filters prepared by the Eastman Kodak Company or the Wratten-Wainwright filters may be conveniently used for this purpose. The transmission of these filters for the different parts of the spectrum is known.

Earlier in the paper it is stated that the apparatus may be also used to mix colored lights obtained with filters and to vary independently the brightness and saturation of a colored light. In order to allow for this the filter-holder noted above is provided with two horizontal tracks or grooves, one just in front of the other. These tracks are just behind the vertical grooves in which the filters are inserted for testing color sensitivity and immediately in front of the projection-lens. In each of these tracks moves a carrier in which may be inserted the appropriate screen or filter. Each of the carriers is operated by a fast motion screw. By means of these screws either of the carriers with its filter can be made to travel back and forth across the beam of light. By varying the amount of this motion the proportion of the beam colored by each filter may be varied at will in a continuous series of changes and the two colors may be mixed in any desired

proportions. A component of white light may be mixed with the colored light by adjusting the position of the two filters so that the beam is divided into three sections, two colored and an intermediate colorless sector. By varying the width of these sectors the proportions of color and white in the mixture may be changed at will.

If it is desirable to vary independently of each other the saturation and brightness of a single color, an opaque screen is substituted for one of the filters. By varying the amount and proportion of the beam intersected by this screen and the filter, the amount and proportion of the white and colored light in the mixture may be varied at will; and by properly selecting these proportions the saturation of the color may be varied and the brightness be held constant or, conversely, the brightness may be varied and the saturation be held constant.

In order that the setting of either screen or filter may be reproduced and to provide for calibration, the filter-holder is provided with two graduated scales, one at the top and one at the bottom. A pointer at the forward end of one of the

FIG. 3. Color mixer

filter carriers travels over one of these scales, and a second pointer at the forward end of the other carrier travels over the other scale.

The mixing takes place on the principle that each point in the image receives light from every point in the lens; therefore the insertion of a colored filter over any part of the lens results in a uniform coloration of every part of the image. This, so far as we know, is the only way in which the mixing of colored lights, obtained by means of filters, can be conveniently and satisfactorily accomplished from a single source of light. The method is a corollary of the method we have used to secure the uniform illumination of a surface from a single source of light, namely the uniform illumination of a small aperture and the projection of its magnified image on the surface to be illuminated. When this is done the light coming from any part of the lens is uniformly distributed in the image. As many colors can be mixed by this method, therefore, as means can be provided for inserting and moving the filters across the beam of light at the front or back surface of the lens. A photograph of the apparatus provided with the color-mixing attachment is shown in Fig. 3.

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